METALLURGIA

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Distribution of Nickel Electroplate Over Irregular-Shaped Articles

By E. E. Halls

The distribution of the deposit is of fundamental importance, and the author discusses the extent of variation in some typical cases. Various methods of determining thickness values are considered and for routine plating shop control it is concluded that the stripping test provides the simplest means of ensuring a satisfactory nominal thickness.

EVEN where it is used for decorative purposes, nickel-plating has a definite corrosion-resisting function to perform. Certain standards have been laid down for thickness of electro-nickel coatings which experience has shown must be maintained if satisfactory performance is to be ensured. This state of affairs has been brought about largely by the use of nickel as an underlay to chromium, in which application it was quickly established by failures in the field that the minimum thickness of nickel was a critical factor. But the same considerations arise when nickel alone is used, or copper-nickel coatings are involved. Again, they hold good in relation to ordinary mat nickel deposits. or to highly polished bright coatings. Most important. of course, is the thickness feature when nickel coatings are on iron or steel as the base metal. There are two prime considerations when fixing a thickness standard for protective metal coatings. The first of these is the thickness of coating shown to be essential for serviceability from the corrosion viewpoint. The second is the limiting factor when moving or mating surfaces have to be treated. In many instances the second of these hardly arises, and the first alone need be catered for. More often, however, especially when dealing with smaller class work, particularly articles of irregular contour for light mechanisms, the second factor not only cannot be disregarded, but it assumes major importance. There is definitely a limit to the thickness of electroplate coating that can be tolerated on miscellaneous articles which have to be assembled under mass production condition. In the case of electrical equipment, there is often a further restriction due to the upset of electro-magnetic functioning if coatings of an indiscriminate range of thickness are provided. Consequently, one is not always concerned with specifying a minimum thickness of metal deposit, but also a maximum has to be instituted, and moreover, compromise between the two prime factors mentioned may cause the minimum limit of the min./max. range to be set below that minimum value established for guaranteed protection relating to service conditions.

During the past decade, engineers and people concerned with electroplating have been educated to appreciate the significance of plate thickness, and to specify finishes in terms of thickness. However, it is stressed, and particularly for the attention of those concerned with the imposition of lower and upper limits, that it is impossible to electroplate an article with the same thickness of deposit over its entire surface. The variation experienced will depend upon a number of factors, of which the chief are the following, assuming a properly controlled plating technique :—

1. The relative position of the article in the plating bath, i.e., relative depth of immersion, distance from

Fig. 1.—Showing irregular nickel deposits.

anodes, and, in case of stationary baths, relative position from ends of vat.

2. Contour of the article.

3. Variation in contact of wiring or racking.

4. Evenness of spacing of articles on wire or rack, or from wire to wire.

5. Shielding created by adjacent articles, or prominences in same article.

Examination of the conditions in any plating vat, and of the ouput from it, readily demonstrates the veracity of these statements. The point emphasised is that when a standard is quoted, the limits specified mean *average* thicknesses over a particular article, and if localised areas or points on the article are tested either more or less than the maximum and minimum limits stipulated respectively will be found in numberless cases, even though the average thickness satisfies the requirements.

As this question of distribution of the plated deposit is so fundamentally important, it is proposed in this article to show the extent of variation in typical cases, but confining the subject matter to this aspect of the problem without expanding unduly into the cause.

Determining Thickness of Coatings

It is necessary, first, to dwell briefly upon the methods of determining the thickness of electro-nickel coatings. The fundamental method of determining thickness on a component is to dissolve the coating off in a suitable acid

mixture, estimate the nickel thereby removed by chemical means, and express the result in terms of a weight of nickel per unit area of surface. This obviously yields an *average* thickness value, which, if desired, can be computed to inches or millimetres of average thickness, assuming the specific gravity of nickel.

For routine work, chemical analysis is too tedious and lengthy, and the average weight of nickel coating per unit area is determined by weighing the component, or if necessary a portion of it, before and after stripping the coating in a suitable acid mixture which is without effect upon the base metal itself. The results by stripping are liable to be a little higher than those from full chemical analysis, and obviously include any impurities plated out with the nickel or held as inclusions, any oxide, and the influence of any slight dissolution of the base metal itself.

The above two methods provide nothing more than an average thickness, and to obtain information in relation to variation of deposit thickness, recourse must be made to microscopic examination of appropriately prepared sections, or to occular projection methods. These again are lengthy and tedious, and demand a considerable degree of manipulative skill. Nevertheless, if a true picture of the coating is required, not only with respect to contour, but also to structure, porosity, and inclusions, the microscopic method is the absolute and precise means. Again, for routine work, a compromise is available providing the results obtained are judiciously interpreted. This method employs a standardised equipment, known commercially as the B.N.F. jet-test apparatus, the latter being a modified and simplified form of the drop-test apparatus used by Dr. S. G. Clarke in his original researches, ref.: Research No. 53, British Non-Ferrous Metals Research Association, November, 1936. This method records the time for a corrosive fluid to penetrate to the base metal, all conditions being standardised, and at any temperature the time being closely a linear function of the coating thickness. Readers are referred to the original report mentioned above for any further information and details. For the present purpose it is sufficient to say that for any given type of nickel plate (with respect to conditions of deposition, electrolyte composition, temperature, current, etc.), the time values obtained by this test yield comparative information on thickness, and from tests on specimens of the same quality of plate of known thickness, it is possible to compute a working formula to convert times to inches or millimetres.

Sufficient has been said upon the above aspect in relation to the present problem ; hereafter, the chemical analysis method will be referred to as " chemical," stripping method as " strip," and the B.N.F. jet test as " drop."

Distribution of Deposit

The fact that nickel deposits irregularly, and does build up on edges, extremities, prominences, and even exaggerates machining or other surface defects, is aptly demonstrated by the photomicrograph in Fig. 1. The component in question was one of a batch plated, nickel direct on steel, to a nominal average thickness of 0·0002 in., the strip test showing an actual average value of 0·00035 in. The article was selected for examination because the plating had obviously built up on the knife edge bearing portion of it, but additionally it was thought the knife edge had been damaged prior to plating. The photograph is × 200, and is the knife-edge portion cut off, heavily copper-plated, heavily nickel-plated, sectioned, mounted in bakelite, and polished and etched in the usual metallographic manner. The way in which the nickel builds up around protruberences is clearly shown, its thickness being from 0·0008 in. to 0·00125 in. Moreover, it enhances the deformities in the knife edge.

Below, the distribution of nickel deposit plated direct on steel in rotary cathode vats is illustrated by practical data on a number of miscellaneous irregular-shaped articles to represent various types.

Square Panels.—Table 1 and Fig. 2 relate to three square

TABLE I.
DISTRIBUTION OF NICKEL PLATING ON MILD STEEL PANELS, 5 IN. SQUARE.
Thickness of nickel by Drop Test in Mils (for Drop Test Positions see Fig. No. 2).

Drop Test Position.	Specimen Number.		
	1	2	3
Back Side 1	0·46	0·54	0·58
2	0·42	0·46	0·54
3	0·34	0·38	0·46
4	0·38	0·32	0·50
5	0·46	0·30	0·66
6	0·44	0·50	0·50
7	0·34	0·40	0·44
8	0·36	0·34	0·50
9	0·40	0·40	0·68
Front Side 1	0·36	0·26	0·32
2	0·24	0·26	0·22
3	0·20	0·32	0·24
4	0·20	0·32	0·30
5	0·24	0·34	0·52
6	0·34	0·32	0·34
7	0·28	0·34	0·26
8	0·26	0·30	0·40
9	0·26	0·34	0·46
Average drop value	0·33	0·36	0·44
Average strip value	0·60	0·94	0·72
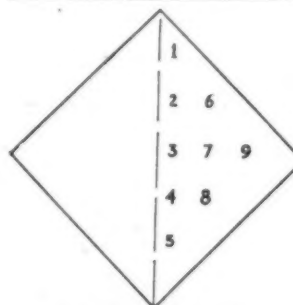
Fig. 2.—Flat panel.
(See data in Table I.)

panels suspended from the same wire in a commercial manner. They were wired from holes in one corner, so that the suspension wire passed across one face of each ; moreover, the plates overlapped in the bath by approximately 1½ ins. The specimen Nos. 1, 2 and 3 refer to top, middle and bottom plates, respectively. To obtain comparative results between drop and strip tests, the panels were cut in halves along the vertical diagonal, one piece used for each test. The following facts emerge :—

1. The thickness of coating is in general lightest in the centres of the plates.

2. Thicknesses of different order exist on opposite sides of the same panel.

3. Shielding effect, due to overlapping, is apparent.

4. Taking so few readings on such a large area, and no readings closely adjacent to or on edges, does not give a fair view of average thickness, as can be witnessed by the average drop value in relation to the average strip value.
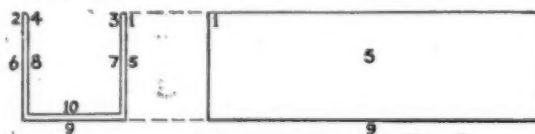
Fig. 3.—Channel.
Positions 1 and 2 on outside corners, 3 and 4 on inside corners, 5, 6 and 9 on centres of outside faces, 7, 8 and 10 on centres of inside faces.

Channel.—The article was selected for examination because it afforded a reasonable opportunity to illustrate the lack of throwing power of nickel into recessed areas. The component does not represent such a severe case as a cupped or box-shaped aticle, but it approaches an average typical case. Even so, in Table 2 and Fig. 3 the marked sparsity of nickel on inner surfaces is clearly brought out, as well as the building up on corners, even inside corners.

TABLE II.
DISTRIBUTION OF NICKEL PLATING ON MILD STEEL CHANNEL, 4 IN. LONG × 1½ IN. × 1½ IN.
Thickness of Nickel by Drop Test in Mils (For Drop Test Positions see Fig. No. 3).

Drop Test Position.	Thickness, Mils.	Drop Test Position.	Thickness, Mils.
1	1·50	7	0·30
2	1·80	8	0·24
3	1·18	9	1·58
4	1·18	10	0·14
5	1·36	Average drop value	1·05
6	1·20	Average strip value	0·91

Cylindrical Shafts.—These shafts were suspended from wires, half a dozen on a wire, the wire being looped around the end remote from that on which No. 4 drop reading was taken. Practical data is given in Table 3 and Fig. 4.

With a round-section article plated in this manner the "adjacent sides" of articles, compared from wire to wire, will be somewhat shielded, whereas those facing anodes will obtain heavier plating. This is borne out by the figures recorded on the curved surfaces, as from the manner of
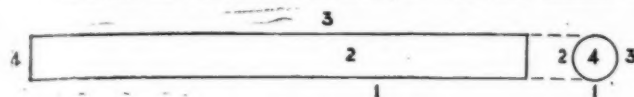
Fig. 4.—Shaft.

Positions 1, 2 and 3 on curved surface, 120° apart, and position 4 on end.

testing one would expect to obtain two high and one low, or alternatively, two low and one high, value. In the case of sample No. 2, evidently the end must have been somewhat shielded, since on all the other samples the end received a definitely heavier plating.

TABLE III.

DISTRIBUTION OF NICKEL PLATING ON STEEL SHAFTS, 6 IN. LONG × ⅞ IN. DIAMETER. Thickness of Nickel by Drop Test in Mils (For Drop Test Positions see Fig. No. 4).

Drop Test Position.	Specimen Number.				
	1.	2.	3.	4.	5.
1	0·99	0·45	1·95	0·52	2·10
2	0·99	0·55	1·49	1·30	1·84
3	1·24	0·65	1·43	0·65	2·18
4	1·18	0·78	2·21	1·43	2·45
Average drop value	1·10	0·61	1·77	0·97	2·15
Average strip value	0·91	0·66	1·83	1·01	1·35

Rectangular Bar with Right-Angle Form.—Results are presented in Table 4 and Fig. 5, drop-test values Nos. 1, 2, 3, 4, 6 and 7 being taken on the long limb, 6 and 7 being edge tests : No. 5 was taken on the flat of the short limb. It will be noticed that tests Nos. 1 to 4 are in general consistent, No. 5 is markedly lower except in one instance, while the edges received considerably more plating, although by no means the same thickness on opposite edges of the same article.
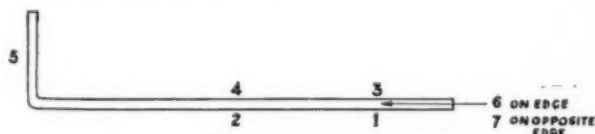
Fig. 5.—Formed bar.

By the illustrations set out above, it has been established that the distribution of nickel plate over various types of irregular shaped articles, as well as over those of regular contour, is extraordinarily ununiform. This is a fact already appreciated in a general way, but the extent to which the variation occurs upon the same article is rarely visualised. On the majority of articles handled through plating shops,

TABLE IV.

DISTRIBUTION OF NICKEL PLATING ON RECTANGULAR BAR WITH RIGHT ANGLE FORM 5 IN. LONG, 1 IN. WIDE, ¼ IN. THICK ; 1 IN. FORM. Thickness of Nickel by Drop Test in Mils (For Drop Test Positions see Fig. No. 5).

Drop Test Position.	Specimen Number.				
	1.	2.	3.	4.	5.
1	2·32	1·55	0·91	1·77	3·30
2	2·24	1·30	1·55	1·64	2·36
3	2·24	1·37	1·62	1·58	2·79
4	2·11	1·37	1·34	1·43	2·71
5	1·09	0·72	1·67	1·09	1·43
6	5·05	3·10	1·30	2·32	4·29
7	2·45	2·42	2·92	1·97	5·25
Average drop value	2·50	1·69	1·61	1·69	3·18
Average strip value	1·88	1·34	1·17	1·06	2·30

unless they lend themselves to the adoption of special measures, rotation, shaped anodes, etc.—which types of object are in the minority with established practices,—a condition exists whereby the nickel thickness will range from virtually nothing to the maximum amount depositable under the conditions obtainable. Granted, the thin areas will present points of weakness with respect to the serviceability of the coating. On the other hand, for economic production a limit has to be fixed for plating time, and in many instances, even with extended times, no further deposition would occur on certain shielded areas, while in other localities the extent of variation becomes more prominent with increased plating period. Again, there will exist other objections to uncontrolled maximum plating time—built up on edges, threads, bearing parts, etc., give trouble in assembly fits, as well as the possibility with the lessening of adhesion with growing thickness.

From the data presented, it will be seen that no relationship exists between individual local thickness values, as determined by the drop test—or their averages—and the average nickel thickness computed from chemical stripping determinations. If the matter is given thought, this is a logical conclusion. It does stress, however, that the drop test serves little purpose other than that of obtaining comparative thickness values for the detection of areas of maximum and minimum thickness. From the point of view of routine plating shop control, bearing in mind commercial features of plating practice, assemblage problems and cost, undoubtedly the stripping test offers the simplest means of ensuring a satisfactory nominal thickness, and the only means of providing for a minimum average and a maximum average. These latter two limiting values must, of necessity, be accepted, the first to safeguard (in conjunction with good plating technique) against excessively thin spots, and the second to provide some measure of control over excessively troublesome build-up. Wisely handled, both forms of test, that is local measurement by drop method, and average determination by stripping, have their indispensable applications.

Silver in Lead-Base White Metals

Some data are given from a preliminary report on the properties of new and very promising lead-base white metals containing silver, developed to provide a replacement material that would closely approach the tin-base white metals in essential bearing properties.

THE increasingly critical tin situation causes the development and the widest possible use of satisfactory low-tin or no-tin alternatives for bearing metals, solders, coatings, bronzes, etc., that ordinarily consume large amounts of that metal. A preliminary report by H. W. Gillett and R. W. Dayton* on the properties, as compared to tin-base white metals and silver-free lead-base white metals, of new and extremely promising lead-

base white metals containing silver is of considerable interest, as these alloys have been developed specifically to provide a replacement material that would closely approach tin-base white metals in essential bearing properties.

In service, lead-base white metals are not considered to be as good as tin-base alloys unless they are used in an extremely thin layer. Recent automobile practice has shown that when used in a thin layer supported by a strong e

* Metals and Alloys, 1942, Vol. 15, No. 4, pp. 584-587.

backing, lead-base metal has proved to be the equivalent of tin-base metal. The addition of a little silver to lead markedly improves its retention of hardness at elevated temperatures, and also changes lead from a very poorly bonding material to a solder of recognised value. It, therefore, seems obvious to expect that silver added to ordinary lead-base white metal might make it much more nearly the equivalent of the tin-base alloy.

A series of experiments were carried out, first, to determine the selection of the best composition of a lead-base white metal containing the usual elements, and second, the effect of hitherto unused elements for obtaining further improvements. In the first part, it was found that the amount of tin in the alloys was critical, since the alloys were weak if either too much or too little tin were present, and that copper was a desirable addition, improving both hardness and bondability. In the second part, it was found that silver was an excellent addition, improving the hot hardness but not causing a corresponding increase in cold hardness, and not at the expense of an increase in brittleness. Bondability was also decidedly improved.

Alloys were made containing various amounts of antimony, tin and copper, and various additions including arsenic, cadmium, silver and tellurium until the optimum range for the new alloys was determined. They were melted in clay-graphite crucibles under a cover of fine charcoal, and poured into steel moulds heated to 200° F. before casting. All the alloys were made of rather pure materials, so that the amount of impurities was small. It was found that apart from those elements commonly used as hardeners, only silver was a really successful addition in all respects. The results of this part of the investigation are summarised in Table I, in which are given data for the best of the alloys tested.

The data included in Table I include hardness, bondability, and ductility. The hardness was measured in Brinell figures, the impressions being made and measured on a Vickers' hardness testing machine, using a 2·5 mm. ball and a load varying from 2 to 5 kgs., depending on the hardness. Hot-hardness tests were made by supporting the test specimens in a hole in a heated aluminium cylinder, and hot-hardness impressions were made with the load applied both for 30 secs. and 300 secs., in order to obtain some idea of the flow characteristics of the materials. The data on bondability were obtained on 2-in. square sheets of steel which had been pickled and fluxed. Small samples of the alloy to be tested were placed on the top of the steel plates, which were then heated with a torch from below till the alloy stopped flowing. White metals which flowed readily were classed as good, and those which did not as poor. Ductility data were found by pounding down cylinders of the material under test with hammer blows of constant impact until the first sign of cracking appeared. The thickness was then measured, and the reduction of height from the original thickness was a measure of ductility.

Comparison of the lead-base alloys with the tin-base alloys shows that the former, though equally hard as cast, lose hardness when aged, and at high temperatures are not so hard as the tin-base alloys. They also flow more readily in the hardness test under long-time loading. To some extent the lead-base alloys can be improved by alteration of their composition. Alloys with a large amount of tin like the first three lead-base alloys are particularly susceptible to loss of hardness by ageing and flow. Reducing the tin content to 2% in an alloy that contains 15% of antimony

reduces the hardness loss at high temperatures. Additions of copper decrease the hardness loss at high temperature due to ageing and flow, and simultaneously improve bondability. Copper, however, decreases the ductility, and this is considered by some users to be undesirable. The best of the lead-base alloys contain 15% antimony, 2% tin, 0·2% copper, and is nearly the equivalent of tin-base white metal, except for bondability and ductility.

Additions of silver to lead-base alloys produce further improvements beyond that obtainable from an alteration of the basic constituents in the lead-base alloys. These improvements in hot-hardness and bondability are obtained without sacrificing ductility. By the use of silver in lead-base white metals, it is possible to produce alloys either of greater strength and equal ductility, or of equal strength and greater ductility, both with improved bondability. The strongest of the alloys produced by the addition of silver contains 5% silver, 15% antimony, 2% tin, and 0·2% copper. This alloy is 20 to 25% stronger than either the strongest lead-base alloy or the strongest tin-base alloy, and its capacity for bonding is far better than of the straight lead-base alloy.

The best of the lead-silver base white metals were chosen for further study. Those were the alloys containing 15% antimony, 2% tin, 0·2% copper and 5% silver, and 10% antimony, 3% tin and 2·6% silver, respectively. They were compared in various tests with the best tin base and the

TABLE I.
COMPARATIVE PROPERTIES OF TIN BASE, LEAD BASE, AND SILVER-LEAD BASE WHITE METALS.

Alloy.		Composition.					Brinell Hardness.				Ease of Bonding.	Ductility, %.
									Age and Test 300° F.			
Type.	No.	PB.	AG.	SB.	SN.	CU.	As Cast.	Aged.*	30 secs.	300 secs.		
Tin Base	398	—	—	7·5	89·0	3·5	19	17	6·0	4·4	—	99
	399	—	—	8·3	83·4	8·3	20	20	7·2	5·5	—	91
Lead Base	401	85	—	10	5	—	21	17	6·4	4·0	—	—
	403	75	—	15	10	—	26	18	6·5	4·2	—	55
	402	80	—	15	5	—	22	17	5·8	3·7	—	—
	400	83	—	15	2	—	21	16	6·4	5·0	Poor	50
	407	82·8	—	15	2	0·2	18	18	7·1	5·4	Fair	40
Lead Silver Base	366	79·7	5·1	15	—	0·2	22	16	6·0	3·8	—	—
	367	77·8	5·0	15	2	0·2	23	21	8·9	6·6	Good	40
	368	75	4·8	15	5	0·2	25	19	7·2	5·9	—	57
	394	75·2	4·8	15	5	—	22	18	6·9	4·7	—	77
	397	84·4	2·6	10	3	—	21	18	7·2	5·2	Good	59

* Aged for 24 hours at 300° F.

best lead-base white metals. Microstructures of the new alloys were similar to those of ordinary bearing alloys. Amsler seizure tests were made, and it was found that there was practically no difference in the results for the various alloys. The two lead-silver-base alloys had a seizure resistance of 3,600—3,900 lb. per sq. in., the lead base alloys a seizure resistance of about 3,500 lb. per sq. in., and the tin-base alloys a seizure resistance of about 3,000 lb. per sq. in. Corrosion tests carried out with two different types of corroding medium—oil whose oxidation was catalyzed by the addition of iron naphthenate, and oil to which 1% of oleic acid had been added, showed the lead-silver-base alloys to be satisfactorily resistant to corrosion.

Tests of full-size connecting rod bearings, 2 in. inside diameter, 2⅝ in. outside diameter, and 1·28 in. long, lined with a 0·020 in. layer of the white metals, Nos. 399, 407, 367 and 397, were made on a bearing machine. The test speed was 3,550 r.p.m., the bearing load 1,100 lb. per sq. in., and the bearing temperature 300° F., and these conditions sufficed to cause fatigue failure of the bearings in a 50-hour test. Three tests were run on each material, and no alloy was found markedly superior to any other.

In general, it is considered that while the new lead-silver-base white metal may not be the equal of a tin-base white metal in all respects, it is the equivalent in the more-important bearing properties, and in a summation of properties approaches those of tin-base white metal more closely than other substitutes. It is also believed that in the present shortage of tin these alloys should find considerable use.

Practical Co-operation

Mutual Economic Endeavour in Operation

FROM time to time we have attempted to direct attention to the need for post-war planning in order that schemes of reconstruction erected on a sound basis may be put into operation with as little delay as possible. It seems clear, however, that the most fertile brains are concentrated on winning the war, but while we recognise this to be of primary importance, winning the peace is very important for the future. It is true that, under conditions of war, planning for the future is much more difficult, particularly when it is a war that threatens to destroy the progress of mankind for hundreds of years, yet we must plan for the future in times of war, especially when it is a war of such proportions as the present. The survivors will face a new world and unless the best brains of this country are directing part, at least, of their energies to post-war reconstruction, the new world will be one of chaos.

The problems, for which solutions must be sought, are many, and all are complex. Industrial problems alone will be difficult of solution. Look at the outstanding facts of the present situation! Millions of people have ceased the production of utility goods, and are concentrating on destruction, while within the actual war zone vast reserves of real wealth in all forms are fast disappearing. Normal production, trade, transport and finance are disrupted as never before. Acute shortages of basic necessities face whole populations in many countries. Yet the productivity of the earth and the productive capacity of mankind will remain.

Reconstruction will be a stupendous task, and at the outset it will be necessary to inspire a spirit of world-wide confidence to counteract the bewilderment which will otherwise prevail. A ray of hope on the building up of this spirit of confidence is the experiment in international relations now in progress between the United Nations, which may have profound repercussions in the post-war period. Opinions, however, are divided regarding the problems of international post-war reconstruction. Many argue that our only immediate task is the winning of the war, and that post-war problems can be settled when they arise. Others contend that final victory, in the real sense, depends upon the clarification and adoption now of plans for post-war action, to be placed in effect immediately upon conclusion of an armistice. The ideal solution, of course, would be some organisation essential to the winning of the war, yet equally valuable as a basis and instrument for post-war co-operation.

The nucleus of just such an organisation is now in being, the wider implications of which are perhaps not yet realised. The United Nations have set up, for purposes of joint action in the conduct of the war, a number of committees. Some of these have very specialised tasks to perform in somewhat limited fields, and their efforts are concentrated on speeding the output of the military and economic weapons of war. Several economic committees, however, have been set up; in particular the Royal Bank of Canada points out in its *Monthly Letter* for June, the Joint Economic Committee of Canada and the United States operates in the whole field of economic endeavour. Such com-

mittees may well form nuclei for post-war co-operation. The work of these committees bears so directly on the war effort that few of their plans or recommendations are made public, but one example may be sufficient to indicate their plan of operation. In April the United States and Canadian Governments announced their approval of an agreement, based on recommendations of the Joint Economic Committee, for more effective utilisation of the agricultural resources of Canada and the United States and for a partial solution of the growing problem of securing an adequate supply of oils and fats. The substance of this agreement is that Canada will increase her acreage of flaxseed and will facilitate the delivery in the United States of flaxseed, oats and barley; the United States, on the other hand, will increase her acreage of oil-producing crops and will facilitate the sale to Canada of vegetable oils or vegetable oil seeds.

A far-reaching plan of effective integration of resources for war has thus been arranged with the least possible dislocation of existing economic and political relationships. Such a practical agreement affords a more sure base for economic co-operation than could any theoretical programme, premised on broad generalities rather than on the actualities of an individual situation. It is surely not too much to suggest that the extension of such methods in the post-war period is worthy of serious consideration.

Another important feature of the general work of these committees is the opportunity afforded for contacts between the men who actually administer the policies thus instituted. These administrators, faced daily with the multitudinous decisions necessary for the conduct of the war, might tend to concentrate upon the solution of domestic problems without considering the total effects of their decisons and regulations. These discussions serve to bring home the real nature of the problems involved in the relations between countries.

Like all practical achievements, the results of such co-operation will be somewhere between the unattainable ideal and the existing fact. Close economic co-operation between the United Nations has been made necessary by war and the experience gained can be used for voluntary co-operation in times of peace. Certainly, to win a war it is not sufficient to secure a military victory. In a total war, such as this is, victories must be achieved on other fronts. The broader aspects of the conflict which are assumed to be awaiting post-war solution are vitally a part of the war itself, as important to success as the purely military phase. History indicates that in many cases the stable part of victory depends not only on military success, but upon a preparedness to meet economic, financial, social and cultural phases of the struggle. All these exist to-day, but they will eventually assume a preponderance which will vary as circumstances change. These phases exist in our present-day problems and must be faced and solved, since we cannot afford to suffer defeat either economically, financially, socially, or culturally, any more than we can suffer final defeat in a military sense. Perhaps this new form of co-operation, based upon the broad application of the principles of mutual tolerance and adjustments in small things as in great, will form the foundation of an improved structure.

Tin and the War

Tin Research Institute Report

PRIOR to the outbreak of war the world's production of tin at 100% capacity was approximately 250,000 tons and normal consumption 150,000 tons, so that regulation of production to maintain an economic price, and research to increase the uses as well as to improve the technique of existing uses, was necessary. Since Japan began the Far Eastern campaign, French Indo-China, Thailand, Malaya, and the tin-producing parts of Burma, and the Netherlands East Indies have been occupied and, as the exports of China must be seriously curtailed, there remains only an amount estimated at between 75,000 and 85,000 tons available for consumption by allied and neutral nations who, if the tin were available, would probably consume at least as large a quantity as the world's pre-war demand.

The main problem has thus become one of how to make the best use of the supplies available by curtailing the use of tin in commodities not essential to the war effort, by improving the processes in essential uses, and by recovering tin, even if the process of doing so would not, in normal circumstances, be an economic undertaking. For these tasks the experience accumulated by the Tin Research Institute is invaluable. For this reason it has been appointed by the Ministry of Supply to advise on all technical questions affecting the use of tin and it is collaborating fully with all Government departments and with manufacturers. It can be said that the Institute is filling the United Nations' need and at the same time its close contact with the momentous changes now being effected is putting it in the best position to further the true long-term interests of the producer nations—all of whom, with the exception of Thailand, are anti-Axis nations—when more normal conditions are restored.

Although the immediate problems concerned with the conservation of the Allied tin supplies are the major preoccupation of the Institute, those researches are being continued which promise to be the most fruitful of result for the increased use of tin when ample supplies are again available, and the work of this Institute during 1941, described in its recent report, deals with that prior to the outbreak of war in the Pacific.

Collaboration with manufacturers and with Government departments in the application of electro-tinning for parts of armaments was continued during the year, and there has also been considerable interest in electro-tinning for small soldering tags, terminals, and clips. Although not dealt with in the report, it is understood that the most important application of this work will soon be seen in the production of specially thinly coated tinplates, as a war economy measure, requiring only one third of the tin used in normal tinplate. Reference is made to the assistance rendered to manufacturers in tinning some kinds of steel which have hitherto been difficult to tin. The Institute's hot-tinning plant was in continuous operation throughout the year on demonstrational work.

Other sections in the report review the progress made in research of tin-rich bearing alloys, foil, and bronzes. In the latter section it is noteworthy that considerable progress has been made in melting and casting technique to provide sound, workable bronzes in high-tin content. These can now be made without recourse to any patented process. The new process involves degassing by melting under a special oxidising flux, deoxidising under controlled conditions, followed by pouring at a definite rate which must be pre-determined for a given type of mould. Bronzes containing up to 14% of tin produced by this process have a combination of high tensile strength and ductility and can be readily hot- or cold-worked. Copies of Tin Research Report may be obtained from the Tin Research Institute, Fraser Road, Greenford, Middlesex.

The Iron and Steel Institute

Presentation of the 1942 Bessemer Gold Medal

THE Diploma of Award and the replica of the Bessemer Gold Medal was presented to Mr. E. G. Grace, president of the Bethlehem Steel Corporation, U.S.A., at the recent annual general meeting of the American Iron and Steel Institute, in the presence of 800 members, presided over by Mr. Tower. The presentation was made by Mr. I. F. L. Elliot, member of Council of the British Iron and Steel Institute.

In introducing Mr. Elliot, the president (Mr. Tower) said : " The Council of our fellow Institute in Great Britain has paid us the great and unusual compliment to express a wish to be here this morning both in spirit and in the person of an official representative. Their representative comes to bestow a signal honour on one of our associates, to whom you have already given the highest recognition for outstanding achievement in the steel industry in this country. It is typical of the unquenchable spirit of the British people that in the midst of a struggle for their very existence they have time to think of individual accomplishment and merit. We bid you welcome."

" On the occasion of this annual meeting of your Iron and Steel Institute,' said Mr. Elliot, " the privilege is accorded to me to make presentations to two old friends, whose outstanding achievements and personal distinction is almost as well known to our members as to yours. First, I have the great honour and privilege of presenting to you, Mr. Tower, this Diploma of Honorary Membership of the Iron and Steel Institute of Great Britain. . . . May the day not be far distant when you can take your place as a member of a representative gathering.

" I have a still greater honour, as the representative of Mr. John Craig, the president of the Iron and Steel Institute of Great Britain, during whose term of office the Award was made, and of Mr. James Henderson, our president for the current year, of presenting this Diploma of Award of the Bessemer Medal for 1942 to you, Mr. Grace. . . . For the period of the war our Institute has adopted the practice of presenting only a Diploma and the replica or the Medal, which accompanies it. It is our earnest hope Mr. Grace, when the time comes, you will visit us in Britain to claim the Medal itself. . . . Our Institute has accorded to the most distinguished representative of your great industry the highest honour which lies within its power to bestow, in recognition especially of his outstanding achievements in the World of Steel, but also of the sure and powerful support which the steel industry of America has given to the British industry in its time of need. . . . I need not remind you of the tragic sequence of events. Looking back, I realise something of the magnitude of the debt which I and those I represent and, indeed, all my countrymen owe to you, Mr. Grace, and to all those present to-day, for the way in which you helped us to shoulder our burden of responsibility and for the magnificent support which you and your industry unhesitatingly gave us."

Mr. Grace, in accepting the Award, replied : " It would not be human not to be deeply moved by the most generous words that you said to me personally in conveying to me the citation from the British Iron and Steel Institute. . . . The United Nations have a job in common. The Steel Industries of Great Britain and the United States are the foundation and basis of that job. But in selecting me for the Award, and at a time most critical in world history is naturally a double satisfaction. . . . I would be most ungenerous and ungrateful if I should accept this honour in a selfish manner. I think I see something broader and deeper back of it. Within myself I know that if I qualify for the receipt of this honour and the tribute paid to me in it, I know it is due in large sense to the help, to the team work, that I have had not only from my own associates, but all of you who are interested in our great Steel Industry in this country."

Chilled Wheels for Streetcars

By William F. Chubb, Ph.D., B.Sc.

A brief description of the production of solid-cast wheels for freighters and street railcars was given by the author in the last issue, in which attention was directed to certain researches undertaken to improve the quality of the product. In this article the results are summarised and conclusions given.

FROM a consideration of the work on solid-cast wheels, given in the last issue, it will be clear from the comparison of structures that the fractures of alloyed and unalloyed streetcar wheels are likely to show important differences. Although the alloyed iron is of slightly lower hardness, its fracture shows a greater depth of chilled metal. This iron also has a more gradual transition between the white and grey portions, and for this reason it is to be expected that such a wheel will be less susceptible to failure under conditions of repeated shock, both mechanical and thermal, such as usually prevail in service.

Hence, as a summary in this study of structures as between a standard streetcar wheel and a nickel-chrome wheel it may be said that the chief difference lies in the character of the pearlite constituent. For instance, in the alloy iron the pearlite is more sorbitic than in the unalloyed material, thereby indicating a stronger and tougher alloy. Further, the structures in the chilled portions of both the flange and the tread, while being essentially similar to those of the standard wheel, show in the nickel-chrome iron a complete absence of coarse graphite immediately beneath the outer surface. The structure is also much finer and fine graphite points are much less numerous. As will be evident, these differences have an important bearing on the behaviour in service.

In the grey section of this wheel, the structure is generally less coarse and the graphite flakes are more uniformly distributed. The pearlite has been very largely transformed into tougher and stronger sorbite. Hence, in consideration of all the above facts, it must be concluded that the nickel-chrome wheel, though of slightly lower hardness at the wearing surface, is a superior wheel in regard to both structure and mechanical properties.

Critical Points

Since wheels of this type, as previously mentioned, are subjected to a heat-treatment before being placed into service, it has been essential to measure the critical points of the new material as a means of determining to what extent the heat-treatment should be modified to develop the type of structure most desired. Accordingly, measurements have been made by the neutral body method in an atmosphere of nitrogen,, derived differential curves being then drawn from the recorded temperature and differential couple readings. During measurement of these critical points on heating the rate of heating was 6°, F. per minute, and during cooling the rate of cooling was 8° F. per minute. The results are tabulated below :—

Type of Iron.	Ac_1.			Ar_1.		
	Beginning.	Peak.	End.	Beginning.	Peak.	End.
STANDARD WHEEL. White iron	1,390° F. 754° C.	1,414 768	1,436 780	1,354° F. 734° C.	1,339 726	1,327 719
Grey Iron..........	1,378° F. 748° C.	1,385 752	1,395 756	1,316° F. 713° C.	1,314 712	1,300 704
NICKEL-CHROME WHEEL. White iron	1,366° F. 741° C.	1,383 751	1,404 762	1,295° F. 702° C.	1,278 692	1,250 677
Grey iron	1,360° F. 738° C.	1,372 744	1,389 754	1,296° F. 702° C.	1,262 683	1,242 647

For the heating cycle, " Beginning " means the temperature at which adsorption of heat in approaching the critical point Ac_1 is first observed, and " end " refers to the temperature at which this adsorption is complete. In a similar way, for the cooling cycle, " beginning " refers to the temperature at which heat evolution is first observed on approaching the critical point, Ar_1, and " end " means the temperature at which this evolution of heat ceases.

These measurements naturally have an important bearing in determining the most suitable form of heat-treatment to provide the desired physical properties and wear characteristics. For instance, it will be seen that the critical points of the nickel-chrome iron are substantially lower than those of the standard unalloyed material, and the possibility of a change in heat-treatment is thus of considerable importance in the manufacture of these wheels. In these initial researches, however, the newly produced nickel-chrome wheel was treated in accordance with standard heat-treatment practice, and while the benefits to be derived from alloying are very obvious, these measurements of critical points suggest that an even greater improvement in structure and properties might be obtained through a change in the heat-treatment cycle.

Fig. 25.—Defective wheel, standard iron, crack close to tread, × 100, unetched.

Fig. 26.—Defective wheel, standard iron, same section as Fig. 25, × 100, etched with 5× nitric acid in alcohol.

Fig. 27.—Defective wheel, standard iron, crack in mottled section, × 100, unetched.

Fig. 28.—Defective wheel, standard iron, same section as Fig. 27, × 100, etched with 5× nitric acid in alcohol.
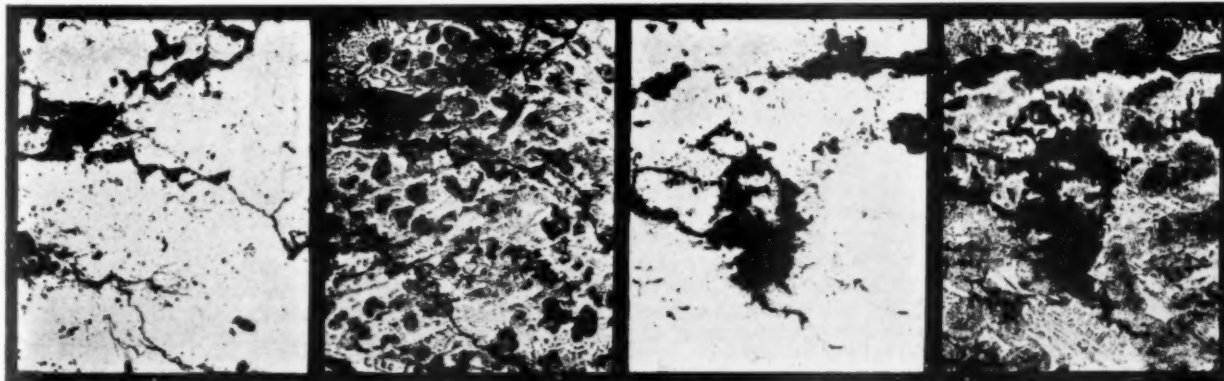
As a further consideration, the relationship between critical points and structure must also be mentioned. It will be apparent that the depression of the Ar_1 point caused by the presence of the alloys will, in accordance with both theory and established practice, help to explain the more ready formation of a sorbitic type of structure and give added significance to the partly spheroidised condition of the pearlite in this type of iron. In the light of these critical point determinations, therefore, a satisfactory correlation between structure, properties and heat-treatment becomes possible.

Conclusion

From the results of this research into the structures and properties of nickel-chrome and plain unalloyed wheels for streetcars it is possible to deduce that chill-cast wheels containing approximately $1·75\%$ of nickel and $0·5\%$ of chromium are in every way superior to unalloyed irons at present generally employed for these services. It must be emphasised, however, that while structures indicating greater strength and shock-resistance are to be obtained by alloying, the hardness at the wearing surfaces of both the tread and the flange is likely to be lower than that obtained in standard chill-cast irons. As a further point of practical interest, it should be noted that in alloying with nickel and chromium it is advisable to increase the percentage of silicon present. In the present instance, the increase in silicon was from $0·60\%$ to $1·00\%$, this being necessary to control the depth of chill and to prevent the formation of a sharp transition between the chilled and mottled sections, which invariably leads to structural weakness. This is all the more necessary since, in service, these wheels may be subjected to great thermal shock during braking, when internal cracks along planes of weakness have a ready tendency to form and to extend with varying degrees of rapidity. These defects may not become apparent for some considerable time, and, as will be realised, the necessity for stable and suitable structures is one of primary importance in chill-cast wheels for freightcars and street railways. By the present research it is believed to have been clearly demonstrated that alloyed irons are likely to provide a higher service performance than a wheel of plain chill-cast iron.

Defective Wheels

It has been mentioned earlier that there may arise during production numerous difficulties leading to the formation of undetectable internal cracks and fissures. In other instances, however, flaws when they occur are not infrequently detected during routine inspection, and as an essential part of this investigation, therefore, an examination has been made of one such failure in a wheel which had two cracks running from the tread well into the mottled section. After selection of an appropriate specimen, the structure observed in the unetched condition was that recorded in Fig. 25, which reveals the appearance of the cracks in a portion close to the tread of the wheel. It will here be seen that the cracks had developed through local nests of graphite, which are much more numerous than is usual in this unalloyed iron. At the same magnification, Fig. 26 depicts the structure of the same area after suitable etching, and here the evidence clearly suggests that the graphite nests were not formed by breakdown of iron carbide during cooling. Etching with boiling picrate confirms this conclusion.

As the cracks extend well into the mottled portion of the wheel, Fig. 27 may be included to illustrate the structure in this section. This photomicrograph shows, at a magnification of 100, that the cracks have again followed lines of weakness arising from the presence of graphite nests, and Fig. 28, also at a magnification of 100, shows the same field after etching with 5% nitric acid in alcohol. The evidence thus provided gives proof that some of the graphite had been produced by breakdown of iron carbide during cooling, this being, of course, normal in mottled iron. Confirmation has been obtained by sodium-picrate etching.

It may be concluded, in this instance, that graphite deposited by breakdown of iron carbide was not the primary cause of the cracks, and the most probable explanation would appear to be that graphite has entered the white section close to the mould-face, thus providing lines of weakness along which the crack initially developed. This crack, it is clear, then extended into the mottled section through graphite areas normally present there due to decomposition of iron carbide during cooling.

United States Emergency Protection Programme

An emergency protection programme designed to make secure the continued production of vital war materials from the United States metal mines, coal mines, quarries, mills, smelters, and allied mineral production facilities is being undertaken by the Bureau of Mines. Integrating its activities with other governmental agencies, the Bureau will co-operate with the Army and Navy, the Federal Bureau of Investigations, and other Federal agencies in a nation-wide unified effort to secure vital supplies, production, storage, transportation, and communication facilities of all types and industries from hazardous neligence and subversive enemy action.

Tentative plans have been submitted by the Bureau which call for the immediate setting up of a specially trained field force in all the mining and mineral producing areas of continental United States and Alaska, in order to achieve and maintain the fullest measures of security to mineral production. Emphasis will be placed upon the primary responsibility of owner-management and, in all cases where possible, the services of local enforcement officials will be utilised.

Under the plans being set in motion by the Bureau a division of Mineral Production Security will be organised comprising two main sections—a Coal Mining Section which will assume responsibility for preparing an inventory of the coal mines and of inaugurating security measures. There are about 6,000 large producing coal mines and about 10,000 smaller ones in 26 states and Alaska, which employ over 500,000 persons, and are scheduled to produce more than 600 million tons of coal this year. The other section, the Metal and Ironmetallic Mineral Mining Section, will establish a security programme for the approximately, 7,000 important producing metal mines employing over 1,000,000 persons, the 2,000 large quarries, and the numerous smelting and other metallurgical plants adjacent to or closely allied with mines and quarries. The work of both these sections will be closely co-ordinated with other units of the Bureau of Mines.

Accelerated war-time demand for coal, strategic metals, and non-metallic minerals have created unprecedented activity in the mining industries throughout the United States, and any interruption in the production or processing of minerals would seriously hamper the war effort. It will be the duty of the Bureau's personnel to safeguard the continued security and operation of the mineral industries and so secure an uninterrupted supply of materials as well as maximum efficiency.

In outlining the plans for the protection of mineral production facilities, Dr. Sayers, Director of the Bureau of Mines, points out that the closing down of certain mines or plants at this time might cause serious slowing down and possible curtailment for a time of the output of planes, tanks, guns, munitions, or other urgently needed weapons for the war effort. Many of the newly-built metallurgical processing plants, where such vital metals as aluminium, magnesium, antimony, tungsten, and chromium are produced, occupy a particularly important place in the United States war effort and the country cannot tolerate the cessation of a single activity through subversive action—a weapon long known to the Axis peoples.

The Influence of Crystal Size and Orientation

Upon the Mechanical Properties of Metals in the Cast Condition

By L. Northcott, D.Sc.

The mechanical properties of a number of binary copper alloys in the cast condition have been correlated with the size and orientation of the crystals. Some tests were also made on pure zinc and pure magnesium in coarse crystal form. The results of this investigation are given by the author in the June, 1942 issue of the Journal of the Institute of Metals, an abstract of which is given here.

INVESTIGATIONS into the influence of crystal size have been mainly confined to hardness determinations on crystallised materials, and the possible effect of the different heat-treatments required to produce different crystal sizes has sometimes been ignored. Very little information is available dealing with the influence of both crystal size and orientation upon the mechanical properties of non-ferrous alloys in the cast condition, and this subject has been investigated.

Ingots were cast by the Durville rotatory method, using a mould arranged for unidirectional solidification. In most instances the macrostructure of the ingot comprised columnar crystals at the bottom and equi-axial crystals above. Columnar crystals, large enough for small tensile test pieces to be cut from them, could be obtained by suitable selection of the casting temperature. The ingots weighed about 21 lbs.

A series of binary alloys of copper with zinc, aluminium, tin, and phosphorus was so prepared. Two types of test pieces were chosen. One having screwed ends and a parallel portion 1×0.2 in. diam., was tested in a standard Amsler testing machine, a mirror extensometer being used. There were many occasions when a smaller test piece was required and for these the Hounsfield tensometer was used. Single notch Izod impact test pieces were obtained from a slice adjacent to an axial slice cut from each ingot.

Results

Zinc Copper Alloys.— Alloys of four different compositions were examined. The α solid solution was represented by one 15% and two 30% zinc alloys, the $(\alpha + \beta)$ structure by a 40% zinc alloy, and the β solid solution by a 47% zinc alloy. As the last two alloys readily solidify in columnar form, the corresponding equi-axial crystal test pieces were obtained from separate ingots cast from the same melt, but at a lower temperature. One of the 30% zinc alloys contained 0.35% iron and 0.07% bismuth, which were added intentionally. The summary given in Table I is representative of the results obtained.

TABLE I.

Crystals/in.²	Maximum Stress, Tons/in.²	Elongation, %.	Crystal Type.
		30% Zinc-Copper.	
56	11.0	58	Transverse columnar.
86	11.9	72	Longitudinal columnar.
1036	13.9	57	Small equi-axial.
3700	16.6	68	,, ,,
		40% Zinc-Copper.	
23	21.2	72	Longitudinal columnar.
66	22.4	44	Equi-axial.
112	22.6	51	,,
426	22.2	46	,,
		47% Zinc-Copper.	
26	22.6	64	Longitudinal columnar.
53	25.8	37	Equi-axial.
89	27.9	34	,,
243	26.9	37	Transverse columnar.

The following general conclusions, following a study of the detailed results, are given by the author; test pieces composed of longitudinal columnar crystals show the lowest maximum stress but highest elongation, transverse columnar crystals give higher maximum stress but lower elongation values, and equi-axial crystal samples show the highest values for maximum stress but low to intermediate values for elongation. Especially in the case of equi-axial crystals, the greater the number of crystals per unit area the greater is the maximum stress but the lower the ductility. Similarly the greater the difference in size between the columnar crystals and the smaller equi-axial ones, the greater is difference in their properties.

It is of interest that the only brass showing a negligible difference in properties between the columnar and equi-axial crystal types is the 60 : 40 alloy, and this is the only one examined which undergoes a transformation on cooling, in this instance to form a mixture of the α and β phases. The tensile specimens of this composition showed even smaller differences in properties than did the tensometer ones.

Aluminium-Copper Alloys.—Alloys of four different compositions were examined, the aluminium contents being respectively 1, 5, and 7%, representing the α solid solution and 10% for $(\alpha + \beta)$ phases. Four ingots of the 1% alloy, having different structures, were examined; one of the ingots consisted mostly of one large crystal, one of several columnar crystals, and two of medium and very small equi-axial crystals, respectively.

The different test pieces of the 1% aluminium alloy show progressively higher tensile strengths with increase in the number of crystals per unit area, ranging from a mean of 8.7 tons/in.² in the single-crystal sample to 14.2 tons/in.² in the sample composed of 3,000 crystals/in.².

The other two α solid solution alloys, containing respectively 5% and 7% aluminium, show a similar effect, the range in the maximum stress of the 5% alloy being approximately 15-21 tons/in.², and that of the 7% alloy 16-25 tons/in.². In all these α solid solution alloys the value for maximum stress is in general least and the elongation greatest in those specimens composed of a smaller number of columnar crystals oriented with their long axis disposed longitudinally to the axis of the test piece; the maximum stress is greatest and the elongation least in those samples composed of the largest number of crystals per unit area, and intermediate values are observed in the columnar crystal samples in which the major axis of the crystals is disposed at right angles to the long axis of the test piece.

Entirely different results are found in the two-phase alloy containing 10% aluminium. In this, the maximum stress remains approximately constant irrespective of the crystal type or orientation.

The results obtained with the single and double-phase aluminium-copper alloys thus confirm those obtained with the corresponding zinc-copper alloys.

Tin-Copper Alloys.—Four alloys, containing respectively 2, 6, 10, and 13% tin, were examined. Fewer data are available, especially with the higher tin alloys, since some of the samples were obviously not sound and the results from these omitted; test pieces from the equi-axial crystal areas were the ones most affected. The results, in general, support those obtained with the zinc-copper and aluminium copper alloys, in that the maximum tensile strength of the single-phase α solid-solution samples varies with the crystal

type and orientation, where this effect is much less apparent in the two-phase alloys. For example, the maximum stress of the 2% tin alloy ranges from 11.3 to 15.1 tons/in.² as the crystal size decreases from 20 to 370 crystals/in.², whereas the values for the 10% alloy remain practically constant at 22 tons/in.² over the range 45 to 500 crystals/in.².

Phosphorus-Copper Alloys.—Two alloys of copper, containing respectively 0.1 and 0.5% phosphorus, were also examined. These two ingots, prepared in a smaller mould (3 × 3 in. diam.) than those previously described, were composed of columnar crystals in the lower half and very small equi-axial crystals in the upper half of the ingot. Two tensile and tensometer specimens in both alloys were cut vertically from the equi-axial region, the remaining equi-axial crystal samples being cut from horizontal positions.

It is shown that, as the crystal size of the 0.1% phosphorus alloy decreased from 189 to 3,180 crystals/in.², the maximum stress rose from 9.9 to 13.6 tons/in.², and the reduction of area dropped from 90 to 70%, the corresponding values for the 0.5% phosphorus alloy with decrease in crystal size from 230 to 4,772 crystals/in.² were : maximum stress 12.3 to 15.6 tons/in.² and 92 to 64% reduction of area.

The results show the improvement obtained in maximum stress as the crystal size is decreased, and the accompanying slight loss in ductility is shown more by the figures for reduction of area than by the elongation measurements. It is of interest to note that the tensile properties of the transverse columnar crystal samples are similar to the longitudinal crystal samples when the number of crystals is similar and are only higher when the number of crystals is much greater.

Hexagonal Metals

The results so far described deal with alloys of cubic symmetry, the α-phase copper alloys being face-centred cubic and the β-phase, body-centred cubic. A few tests were made on metals having the hexagonal lattice structure. Tensile tests were made of samples cut from zinc and magnesium ingots, of 99.99+% and 99.92% purity respectively, and the results are summarised as follows.

Zinc.—Test pieces composed of six longitudinal crystals gave maximum stresses all close to 3.4 tons/in.², as against a mean of 1.1 tons/in.² for test pieces composed on an average of 21 transverse columnar crystals. In the case of two other ingots cast from one melt to give wholly columnar and wholly equi-axial crystals, the maximum stress values were 3.3, 0.9, and 2.1 tons/in.² for test pieces in which the crystal structures were, respectively, longitudinal columnar, transverse columnar, and equi-axial.

Magnesium.—In three ingots cast at different temperatures, the maximum stress values were 5.9, 7.1, and 10.9 tons/in.² for longitudinal columnar crystal samples, and 3.6, 5.1, and 4.7 tons/in.² when the columnar crystals were disposed transversely.

In the tests on the magnesium samples, the yield-point, judged by the drop in the beam, occurred between 1.76 and 1.92 tons/in.², and there was little difference in elongation between the different specimens, the average figure lying between 2% and 3%.

Micro-examination of the magnesium test pieces under load revealed the general mode of failure of magnesium to be similar to that of zinc as regards development of slip and twinning. Both forms of deformation were prominent, and slip was more general in the magnesium than it had appeared to be in the zinc. The actual fracture in magnesium was not so obviously of the straight-cleavage type and was preceded by more local deformation.

It is clear that the tensile properties of these hexagonal metals differ in two important respects from the face- or body-centred cubic alloys described above. In the first place there is a considerable difference in the properties of the columnar-crystal aggregates tested in the longitudinal and transverse direction, the former showing a maximum-stress value as much as four times as great as that of the latter, in the case of zinc. In the second place, the maximum

stresses of the equi-axial crystal test pieces are not greater than those of the columnar crystals taken as a whole, but are intermediate in value between the maximum stresses of the columnar crystals tested longitudinally and tested transversely. This feature seems reasonable enough when the mode of deformation of these hexagonal metals is considered. It is clear that, with the samples of the hexagonal metals examined, the grain-boundary effect is outweighed by the directional properties of the crystal itself.

Notched-bar Impact Tests

In view of the influence of grain-size upon the impact value of steels, it was anticipated that appreciable differences in impact value would be found in the present non-ferrous alloys. This has been found not to be so. Considerable differences did occur between alloys of different compositions, as would be expected, ranging from 0.5 ft.-lb. for a 56% zinc copper alloy to 60 or so ft.-lb. for the 40 and 47% zinc alloys, but the impact values of samples cut from the same ingot were sensibly the same. Where appreciable differences did occur it was evident that the lower values resulted from unsoundness in the ingot, and for the most part this was limited to the equi-axial regions in the higher tin-bronze ingots.

Thermostatic Bimetals

BIMETAL is the name given to a range of composite metallurgical products, generally in the form of sheet or strip, consisting of two metals possessing different coefficients of thermal expansion, firmly united by riveting, soldering, or best by welding. For many years bimetal strips or discs have been employed to an increasing extent in the electrical industry, and in the construction of simple and economical apparatus designed for operating at a pre-determined temperature, or for continuously controlling temperatures.

In these two instances the use of the bimetal is fundamentally different. In the first case it must operate only at a single determined adjustable temperature, its behaviour at higher or lower temperatures being of no consequence in this instance. In the second case it must serve as a measuring instrument for the widest possible temperature range, and the continuous alteration in its characteristics should be as uniform as possible between these temperature limits.

Metals having the lowest coefficients of expansion do not have straight lines for their expansion curves ; they are divided into a slightly inclined part at lower temperatures and a steeper part at higher temperatures.

The change from a low to a high coefficient of expansion takes place at different temperatures, so that the element having the low coefficient of expansion must be suitably selected, depending upon the required working temperature. If the temperature range over which the bimetal strip is to work lies between room temperature and 120° C. maximum, a nickel-iron alloy (35% nickel), known as " Invar," is used, preferably, as the component with a low coefficient of expansion. Up to 230° C. a 40% nickel-iron alloy, up to 340° C. a 42%, and up to 440° C. a 46% nickel-iron alloy are most advantageous.

Many metals may be used for the strip with the highest coefficient of expansion, but many factors must be considered in making a choice. It is necessary, for instance, that the elastic properties of the material should be sufficient to resist the internal stresses which develop at elevated temperatures and under heavy loads. Brass is commonly used, but for high-temperature work " Monel " stainless steel, and many of the nickel-chromium-iron group have been utilised to replace brass, on account of their superior mechanical properties. Much data is given in a recent publication* which will assist designers to choose a suitable grade of material for any specific application, and enable them to obtain the best results consistent with economy.

Nitrided Cast Iron as an Alloy Steel Substitute

By Bernard Thomas, F.Inst.P., F.Inst.F.

The application of nitrided cast iron for clipping tools to remove the "flash" from drop forgings is considered in comparison with several alloy steels. In practice, the nitrided cast iron not only proved advantageous in the production of the tools, but offered very much longer life in service.

IN these days of alternatives to avoid using alloy steels, mention of nitrogen-hardened cast iron for use as clipping tools in the drop-forging industry might be of interest. As is probably well known, Dr. J. E. Hurst has contributed largely on the subject of nitriding, but there does not appear to have been extensive application with cast iron in practice since his publication in 1932.*

All drop-forgers and stampers will be familiar with the so-called "clipping tools," which are used in a press adjacent to the stamp for the purpose of removing the fraise or "flash" of metal which is forced out between the top and bottom dies as surplus to the die impression. It was on such tools that the experiments embodied in these notes were carried out.

As the operation is executed on the forging while still at a red heat from the stamp, work of arduous nature would not appear to be involved. Unfortunately, however, from time immemorial, it had been a habit to use that ambiguous material bearing the euphemistic title of "best cast steel," and the latter, being only plain carbon content, was invariably quickly "drawn" or spoilt in temper, with the result that early failure was only a question of time.

In some instances where forgings of fairly simple design were involved, even ordinary cast iron had been employed for clipping purposes, but the urge for production made it necessary that materials capable of longer service be used.

First departures made from the use of the ordinary materials were tests with various types of proprietary brands of heat-resisting and hot-working steels. As would be expected, longer periods of working were obtained from these special types, but it was somewhat surprising to find that the unit cost of production was higher in such cases than it was when using even cast iron. This higher figure was largely due to the amount of work obtained being insufficient in comparison to outweigh purchase costs plus toolmaking charges, which is more the exception than the rule with many alloy steels.

Further disadvantages lay in connection with heat-treatment. Firstly, liability of distortion with intricate shapes appeared more pronounced with the higher-alloyed material, resulting in some instances in the scrapping of a completed set of clipping tools—always an intolerable circumstance. Secondly, fully treated tools were frequently too hard either to adjust, if not quite right when new, or to "touch up" after seeing some service. Such conditions rendered it necessary to soften and subsequently re-harden, causing inevitable and undesirable delay.

There were, however, some redeeming features, such as less breakage on irregular shapes, and in these instances at least, production costs were lower, providing distortion was absent following heat-treatment. Further advantage lay in the facility of being able to use a lighter section, with the offer of equal strength to formerly, in addition to neater design in service and appearance.

In view of these latter advantages, a further step was to try tools made of air-hardening nickel-chrome steel of 2S28 (5005–502) composition, with the idea that as the

* "Some Experiments on the Nitrogen-hardening of Cast Iron." J. E. Hurst. *Journal Iron and Steel Institute*, 1932, No. 1.

heat-resisting properties were certainly no whit less than a cast steel, the other possibilities offered should make it a success. In addition, the treatment of 2S28 was very simple, involving air cooling for hardening, which reduces distortion risk to a negligible quantity, and furthermore, despite a high tensile strength, it was possible to file quite easily after treatment if modification was found necessary.

Unfortunately, the high hopes were not sustained by facts. While results in general proved superior to the higher-alloyed types, certain disadvantages caused its use to be restricted to a narrow sphere.

The idea of using nitrided steel had been contemplated, but the necessary oil-quenching prior to nitriding to obtain core strength was a serious drawback on intricate-shaped tools.

It was only natural that the cast iron should be considered, however, in view of its close relationship to the nitrided steel. Nitrided surfaces offer heat-resistance and strength as well as hardness, and reduced tool-making times could be visualised by reason of being able to cast the iron more nearly to finished shape as an alternative to machining from the solid.

Accordingly, therefore, a pair of tools was cast to pattern in nitrogen-hardening quality cast iron. Outside dimensions, being of no great importance, were cast to size, but working faces were left $\frac{1}{8}$ in. full to allow for machining.

On examination, the castings were found to be of close texture and remarkably free from blowholes, to the extent that when ready for nitriding the polished working faces resembled steel. These latter faces, when rough machined, were left a matter of $\frac{1}{32}$ in. full in order that any areas decarbonised during the preliminary heat-treatment could be subsequently removed prior to the hardening in nitrogen.

After rough machining, the preliminary treatment given consisted of heating slowly to 900° C., allowing to soak for a few minutes and then cooling off in weak air-blast. As the special iron had air-hardening properties, this treatment not only strengthened it, which is a necessity in order to support later the hard face, but also produced the physical conditions most suited for the penetration of nitrogen.

Finish-machining was then executed, the iron offering no difficulties in the way of hardness. The precaution was taken of substituting a slight radius on all sharp corners in order to reduce the risk of spalling through penetration occurring from two directions.

Nitrogen-hardening was carried out as in the usual way for steel—that is, the tools were included in with a batch of steel parts (there being no other iron ones available), and given the usual 90 hours treatment at 500°–510° C. On withdrawal, their appearance closely resembled that of treated steel parts.

In service the tools were extremely successful, as will be noted from the figures in Table I. Clippings were clean and seizures few. Temperatures of working had no effect on the nitrided surface hardness. Curiously enough, although the material was too hard to file, and which point was cited earlier as a disadvantage, the absence of distortion during production, coupled with the infinitely

longer life offered, rendered it almost unnecessary for any touching-up during use.

TABLE I.

COMPARISON OF PRODUCTION FROM VARIOUS MATERIALS.

Material.	Average Clippings per Set of Tools.
28-28 Ni-Cr steel	3,600
Grey cast iron	4,200
Typical chrome H.R. steel	9,000
Nitrided cast iron	30,000

In fairness to the Ni-Cr steel, it should be explained that after the trial stages its use was confined to the more difficult jobs prior to the introduction of nitrided cast iron, hence the low average clippings yielded per set of tools. Apart from such average, no Ni-Cr tools had been known to exceed a life of 5,000 operations, even on straight-forward work, so that there was no question of it being equal to the special iron for this work.

With the nitrided cast iron, scope is offered in the direction of not only casting to shape as mentioned previously, but holes may be cored for the purpose of bolting down to beds. In addition, it is possible to consider development along the lines of casting surrounding edges in relief to an extent of possibly ½ in., which would still further reduce tool time and charges. Admittedly, manufacture of patterns becomes necessary, but these once made are available for further requirements, while their cost is more than offset by the longer life of the nitrided tools.

The Grinding of Cemented Carbide Tools

By A. J. Schroeder, D.Sc.

The degree of success achieved in machining operations with cemented carbide tools is dependent largely on the condition of the tools, thus the grinding of these tools is of great importance in the present production drive. The technique is different from the grinding of cast carbides, and particular attention must be given to the grinding agent. These are discussed with a view to obtaining maximum efficiency from the tools.

METALLIC carbides are used to an ever increasing degree in workshops, mainly as tools for metal cutting work. Their complete economic exploitation, however, is possible only if the edges of the tools are in the best condition. Because of their type of structure and immense hardness the edges of metallic carbides can be dressed only by grinding. Grinding is, therefore, of great importance to carbide tipped tools.

Cast metal carbides (e.g. stellite, acrite, percite, etc.), which are principally alloys of cobalt, chromium, or tungsten may be ground like high-speed tool steels. Thus, for their machining, grinding wheels manufactured from corundum are sufficient. The grain sizes of the grinding wheels used for cast metal carbides are also hardly different from those applied to high-speed tool steels. During the grinding of cast metal carbides greater regard than in the case of high-speed tools must be paid to the fact that the tools must not be harshly cooled as cracks are the inevitable consequence of such treatment. Cast metal carbides are regularly ground wet for the sole reason that they and high-speed tool steels may be ground on the same wheels. Hence, no special remarks need be made upon the grinding of cast metal carbides, inasmuch as the skilled grinder is enabled to apply to this all his knowledge and experience acquired by grinding tools of high-speed steel.

The grinding of cemented hard carbides which is the exclusive subject of the following discussion is quite different. The great hardness of this group of metallic carbides necessitates the use of a very hard grinding agent which is strong enough to attack cemented carbide. Also the structure of the cemented carbides altogether diverges from that of the older cutting materials. Both high-speed steel and cast metal carbide have a structure that consists of an accumulation of crystallites bonded closely together by considerable cohesive power. On the other hand, cemented hard carbide is manufactured from powder by a metallurgical method, and consists of a mechanically produced, tightly packed, accumulation of carbide grains connected by the binding metal, usually cobalt or nickel. During the sintering process of the hard metal substance only the binding metal melts, since the sintering temperature lies a little above the melting point of the binding metal. The sintering temperature is chosen merely high enough so that the molecular attractive forces between carbide grain and binding metal ensuring the firm cohesion of the whole sintered substance become liberated. This cohesion of the alloying constituents is strengthened by diffusion phenomena which may appear between binding metal and carbide grain. The forces prevailing between the structural constituents will not have the same magnitude as those in cutting materials produced by melting. It is to be expected, therefore, that a breaking-off of individual grains of carbide is more probable in machining a sintered body, i.e. in grinding, than a division of a carbide grain through detachment of a cutting.

If, when considering the grinding process of metallic carbide bodies, these properties are taken into account, we can explain a good many phenomena which are different as compared with the grinding of forged or cast cutting materials, or which at least required certain precautions. Because of the great hardness of the heavy cemented carbide grains, of which almost without exception the carbide metals (e.g. tungsten carbide, tantalum carbide, titanium carbide, etc.), consistent abrasives must be used, the hardness of which surpasses the hardness of the carbides, or is at least equal to it. Silicon carbide which somewhat exceeds the metal carbide in hardness is, therefore, most commonly applied as a primary material for grinding wheels. Boron carbide which is still a little harder than silicon carbide has not yet been used extensively, although metallic carbide can be quite well ground by this material. The only material that is really capable of cutting carbides is diamond, and this has, therefore, come into widespread use for the dressing of cemented carbide tools. Because of its high price, the application of diamond as a grinding agent has been mainly confined to finishing the cutting edges.

As the hardness of silicon carbide is only a little different from that of cemented carbide, and as the latter is, besides, a brittle body owing to its structure, a cutting process in the usual sense such as can be recognised by the kind of formation of a cutting when grinding tough materials, cannot be expected in grinding cemented carbide. If the grindstone dust produced when grinding cemented carbide is inspected through the microscope, one can discern, among the multiplicity of grains of the abrasive broken out, grains of cemented carbide which have distinct surfaces of fracture, and which in consequence must have broken out of the structure. Only seldom can a smooth, glossy surface be observed, indicating the fact that this surface was caused by a cut. The grinding grain actually cuts the grain of

cemented carbide only to a limited degree, and its cutting edge blunts off quickly in consequence of the small difference in hardness. Owing to this an increase in grinding power is required, which either sets free the grain of cemented carbide out of its structure or, however, causes the grinding grain to burst. Only seldom, therefore, can blunted edges be recognised on the beautifully formed, bottle-green crystals of silicon carbide in the microscope ; they give altogether the impression that they had burst during the grinding process.

Also, the grain of cemented carbide is violently forced out of its bond by virtue of the increased cutting power. This fact is about the most important reason why the perfection of the edge depends to a very high degree on the grain size of the abrasive. Because of this, an edge sharp and free from serrations cannot be achieved in one operation, except if only slight quantities of material are to be removed, and a fine-grained grinding wheel is used. It is usually necessary to produce the required fineness of the edge after rough grinding final grinding, in a given case by fine grinding or lapping. Moreover, the grain size of the rough grinding wheel is modified by the size of the cemented carbide tip which is to be ground, since it is clear that the detachment of material during rough grinding of small tips must not be so great as for large tips.

Again, in conformity with the observation of the grinding process it is easy to understand the demand that the direction of grinding must be towards the tip so that the grinding grain " enters " the body of the cemented carbide. Otherwise, if we have the grinding grain " leaving " the cemented carbide, disproportionately large particles of cemented carbide are broken out of the top of the edge so that it becomes very irregular, which means an increased loss of material and time at the very least.

Experiments on grinding cemented carbide tools with the usual tool grinders have frequently been made not by hand but with automatic feed. In by far the most cases only bad results have been obtained when the process was not observed during grinding. The reason for this difficulty has to be traced back to the emulation of hardness between cemented carbide and grinding wheel. When pressing correctly and lightly by hand, grinding wheel and cemented carbide leave between each other so much space that the grains broken out of cemented carbide and abrading agent can roll through. On the other hand, grinding waste is pressed into both materials during the fixed feed so that strong local pressure actions arise which ordinarily overload the cemented carbide and gradually lead to the complete crumbling of the tip. As the grinding grains can no longer cut freely considerable heating appears favouring this process of destruction. When the setting is rigid grinding is, therefore, only possible if very small feed, soft wheel grade, and fine grit are applied.

It is not practical to grind the shank of the tool and cemented carbide tip in the same operation. The steel chips clog for the great part the " pores " between the grains and binding material of the wheel and prevent the breaking out of the grinding grains. Since only really sharp grinding grains in not too hard—or rather, tough—bond are capable of detaching material from a cemented carbide tip, the wheel will soon no longer have effect. The clogged wheel induces the operator to apply immoderate grinding pressure, and finally leads to high degrees of heat which result in grinding cracks and useless tools.

The sensitiveness of cemented carbides to intermittent strain absolutely necessitates that the grinding wheel runs exactly true. An imperfect, little attended wheel is frequently the reason for bad results in grinding. The edge becomes notchy and imperfect, and very often shows cracks. To trim the wheel by means of a wheel dresser is advisable, even if more grinding wheels are thus consumed.

Usually the speed of the wheel is about 80 ft.-sec. for manual grinding ; when grinding with special wheels a speed up to 150 ft.-sec. has proved successful. The pressure of the tool on the wheel may be only light. Heavy pressure leads solely to increased wear of the grinding wheel, not to mention at all that the tip is damaged by cracking or crumbling. It may be said that any visible formation of crack in the tip sometimes takes place only several hours later as when grinding incorrectly the body of the cemented carbide gets stresses that will gradually lead to fracture. Even the certain dull colouring of the freshly ground surface ought to be considered suspiciously.

When grinding cemented carbide, special attention must be paid to correct cooling. The cooling jet must overflow the grinding place in a continuous calm stream so that the cemented carbide tip is permanently wetted by the cooling agent. Partial cooling by a dripping liquid is far more dangerous than no cooling at all. It is entirely wrong during grinding to immerse the tip in water at more or less long intervals ; cracks will be the inevitable consequence. If the grinding process must be interrupted, in the absence of a good cooling arrangement, because the tool becomes so hot that it cannot be held by hand any longer dip the tool shank into water without wetting the tip. If only a small quantity of materials is to be ground, e.g. in final grinding, it is best to grind dry.

The grinding of tools in a fixed setting meets with considerable difficulty for reasons such as demonstrated above. Yet it can hardly be avoided in the dressing of the several kinds of tools, for example milling cutters, inserted tooth cutters, reamers, etc. The measures mentioned are only a make-shift, because they must result in increased employment of time and augmented attention to the grinder owing to the small feed. One's efforts are, however, crowned with success, if the grinding speed is greatly reduced to about 20 ft.-sec. to 40 ft.-sec. At these low speeds the grinding grain has a chance to break out of the structure and, besides, when rolling through, to produce the desired effect between the wheel and the body of cemented carbide without causing deterioration of the latter. This process may be characterised as " rolling grinding." It is commonly known that when reducing the speed the grinding wheel seems to get softer ; the same observation may also be noticed when grinding cemented carbide. This phenomenon is fully explained by the splitting of the grain in consequence of the longer action of the compressive strain on its embedding within the bond and it may, therefore, break off more easily. As the loosely rolling grain continuously scrapes against the body of cemented carbide with new, sharp edges, it will even now detach material, if only in small quantities. The quality of the grinding surface is very satisfactory, and also breaking out of the edges is much reduced. The resulting grindstone dust must be continually washed away by a good cooling liquid. The wear of the grinding wheel may be great when using reduced grinding speed and when choosing an exorbitantly large feed, for without difficulty it is possible to turn grinding wheels with cemented carbide tools. Definite care must also be applied in this grinding method in order to produce economic grinding in a fixed setting. Grinding with low speed is of special importance when machining very little cemented carbide alloys which, however, are not usually to be found on the market. In such cases, the only correct method is grinding with a speed from about 26 ft.-sec. to 33 ft.-sec. even when done by hand in order to avoid cracking of the tip.

Owing to the above described operations, no perfect, smooth cutting edge will be attained by the grinding which is usually done with wheels of coarser grain, after the first dressing of the cemented carbide body. The cutting edge is in the majority of cases crumbled-off in numerous places, and it feels notchy when passing along the surface of the edge with the finger nail. This condition is considerably improved by a subsequent grinding operation with a finish grinding wheel of finer grain so that a final ground tool may be used even for rougher work, for example in rough

turning in particular the skin of a casting or forged work. For finishing, however, particularly for final finishing, the fineness of a final ground edge is not yet sufficient. The crumbling-off causes the top rake angle in its outermost margin of the edge to assume widely different values that vary along the whole of the length of edge from serration to notch. Because of this, the free discharge of the chips is impeded, and particles of material in the notches may even bind firmly which is similar to a fusing edge. Whilst the fused edge may occasionally separate from a smooth edge, the accumulations of the machined material pack into the notches, exert a lateral pressure against the grains of the cemented carbide which are already strongly stressed by the cutting process, and gradually force these out of their bond. The result is that the cutting life of a jagged edge is only one-fifth to one-tenth of that of an edge free from notches, as experiments have repeatedly shown.

There are several possible ways of obtaining a proper cutting edge free from notches. The simplest way is to true the edge with a fine-grained whet stone. The truing must be very carefully done, and the whet stone must be directed nearly parallel with the top rake plane or the clearance plane of the main cutting edge with a slight pressure. The top rake angle or the side clearance angle that has been produced by grinding ought to be only halved at the most by truing. The machining motion must be directed towards the cutting edge, if necessary also at an acute angle thereto. On no condition is it allowable to direct the whet stone away from the cutting edge, because in that case grains of cemented carbide may break off afresh, and a proper edge will never be attained. The edge may even be slightly rounded (radius about 0.004 in.) for tools used for roughing work. By this means, the truing process is shortened without evident impairment of the cutting process. The operator who performs the truing operation—everybody who uses cemented carbide tools should normally do this—must be instructed that the edge is to be completely free from notches in order to attain the desired increase in the tool life. A magnifying glass is, therefore, in practice handed over to the workman in addition to the whet stone lest he might be dependent on the feeling of the edge by his finger nail. The loss of time bestowed on the truing of the edge is made up for by the benefit of a longer life of the tool and its more careful treatment in an increased degree.

The importance of a proper edge has also brought about the use of special fine grinding and lapping wheels for the dressing of the cemented carbides. So far as silicon carbide wheels of the finest grain size are concerned, no particulars need be mentioned here. When using such wheels attention must be paid to the fact that they may easily give rise to a profusion of heating and they are, therefore, preferably applied with a cooling agent. Diamond powder is used as a further cutting material for fine grinding and lapping of the edges of cemented carbide, since only diamond has the power actually to cut cemented carbide.

Two principally different sorts of diamond wheels are in the trade. The metal wheel—usually cast iron—coated with loose diamond powder was borrowed from the technique of gem grinding. When using this kind of wheel, the lapping process corresponds again to " rolling " grinding, because the diamond grain is effective both in cutting and, likewise, in rolling. A very satisfactory cutting edge on the cemented carbide tool can be attained by relatively simple means using this lapping method.

In late years fine grinding wheels which contain the diamond powder in firm bond and which are misnamed lapping wheels have been introduced besides the above-mentioned lapping wheels, the applied diamond of which must be renewed from time to time. Artificial resin or hard rubber is used as a binding material for such wheels. Their diamond grain works, in fact, by cutting, since it is firmly fixed in the bond and, in that manner, machines the cemented carbide with an edge embedded relatively firmly.

The cutting power of these fine grinding wheels with diamond in bond is greater than that of the lapping wheels with loose grain. The fine grinding process is, therefore, finished in a shorter time. In spite of the apparently high price, these diamond wheels with bonded grain are absolutely as economic as the cheaper lapping wheels with loose grain, because several thousand edges can be fine ground according to shape and size up to the limits of wear. Truing of these wheels is, naturally, inappropriate considering the high price of the effective material.

There now arises the question when the edge is to be trued only, whether it is to be fine ground by bonded diamond powder, or lapped by loose diamond powder. The grain of the whet stone is capable of only scratching the grain of cemented carbide, and the surface of the intrinsically effective carbide grain remains nearly intact. When truing the superfluous carbide grains are, therefore, knocked out of their bond, similarly as when grinding with reduced speed, so that the surface of the edge trued remains rough. Moreover, this roughness must be expected because of the grain of the whet stone. The resulting chips are chiefly borne by the peaks of this rough surface and, consequently, will not come in any very close contact with the single cemented carbide grains, particularly not with the binding metal. On the other hand, when fine grinding with bonded diamond grain and when lapping with loose diamond powder, the carbide grain is cut, and, therefore, the surface will be very smooth, setting aside the fine cutting marks of the diamond grains. The cutting surface of the carbide grain and the binding agent lie within the same plane which is now under the pressure of the chip sliding over. It has been ascertained by experiment that the formation of a fused edge in edges ground or lapped by diamond can only be avoided by using higher cutting speeds as compared with cutting planes purely trued. The affinity proportions which may be assigned for the explanation of the fusing edge have apparently substantially altered between the material (especially steel) on the one hand and the intact carbide grain or the cut carbide grain on the other so that, indeed, a discrimination of their effect in the cutting process exists between truing and fine grinding with bonded diamond powder or lapping with loose diamond powder. This supposition is confirmed when observing that the edge fine ground or lapped by diamond is inferior to the trued edge with regard to service life within the range of certain cutting speeds. The edge fine ground or lapped by diamond must be just preferred to the edge that is only trued when using cutting speeds which in no case will bring on the formation of the fusing edge. Naturally, the material to be machined plays a part of great moment in this matter.

Thus the sphere of application is set for the various machining methods. If for any reason the cutting speed can be chosen only high enough to lie within the domain of the fusing edge, truing of the edge with the whet stone will be opportune. On the other hand, if a sufficiently high cutting speed which safely oversteps that domain is used, the edge fine ground with bonded diamond or lapped with loose diamond powder will yield advantages which must, under any circumstances, be pursued when, for example, final finishing.

Monel Notes

The recent issue (No. 25) of this useful publication contains articles on the spinning procedure for Monel, nickel, and Inconel methods of etching as used in the production of name plates, low temperature properties of Monel, perforating high nickel alloys, and the value of segregating scrap. Figures showing what American manufacturers have done in the way of recovering alloys from scrap are quoted. An informative note is also included on nickel copper alloys in sea water. Copies may be obtained from Henry Wiggin & Co. Ltd., Grosvenor House, Park Lane, London, W.1.

There is a special need for every ton of steel capable of being produced in this country. It is not only essential for the manufacture of the numerous war weapons, but it constitutes the main structural material for practically every industry contributing to the war effort. War demands far exceed normal plant capacity, but great efforts have been and are being made to increase production and thus to effect some relief in shipments. Increased production, under emergency conditions, has raised many problems, some of which are briefly outlined.

STEEL

WITHOUT in any way reflecting on the importance of numerous other materials in the successful prosecution of the war, there can be no hesitation in acknowledging the vital importance of steel. The demand for increased weight of armament, expressed from time to time, really means a greater amount of steel brought to bear upon the enemy by concentrated effort. Steel combines strength, workability and cheapness to a degree unparalleled in any other material of construction.. It is the mainstay of engineering, indispensable alike in peace and war. Thus, not only is steel of vital importance in the manufacture of efficient weapons of war, represented by the various warships in the Royal Navy, the mechanised equipment of the Field Forces, and the planes and equipment of the Royal Air Force, but it constitutes the main structural material for practically every industry contributing to the war effort.

The world-wide character of the conflict and the highly mechanised equipment applied which greatly increases the speed of the various encounters makes tremendous demands on the producers of steel and, in order that the conflict can proceed with the utmost resources at our disposal, the demand for steel will tend to increase and will perhaps involve stricter control to ensure that production is directed to those channels which contribute to the war effort.

It is fortunate that during a few years prior to the outbreak of hostilities, the iron and steel industry in this country had undergone many and far-reaching changes, both in regard to extension and modernisation of plant and in the introduction of a large measure of unification. Increased output and greater efficiency of plant have resulted. Many extensions have since been carried out, but greater attention has been directed to adjustments in the design of existing plants with a view to increasing their productive capacity.

It has long been recognised that there is a need for every ton of steel that can be produced, and every producing unit and process is under careful study so that it may be operated to capacity, or even its capacity increased. Speeding up in the manufacture of steel, however, is not so easy as it may sound ; it is complicated by the fact that the quality of the steel must be maintained and by the fact that emergency conditions have restricted the supply of materials normally available to the steelmaker in abundance. The quality of the steel must satisfy recognised standards, and for armaments in particular the standards are high.

The problems associated with increased production, while still maintaining the quality of steel produced, is further aggravated by the restrictions in the use of elements that, due to transport difficulties or other causes, are in short supply. The need for the conservation of alloying elements has not only eliminated many of the alloy steels formerly in regular production, but has led to the development of many low alloy steels, some of which were used formerly, though not widely, while others were new to this country. A number of emergency standards have been framed for many of these steels, but it will be appreciated that the conditions involved have greatly intensified the problems of the steelmaker.

A gun of very large calibre now in use by the British Army. It is a super-heavy railway mounting gun. (A News Agency photograph.)

There is another important factor, however, which has also intensified the problem of the iron and steel industry to increase production ; a much greater quantity of native ore is being smelted, and as the average iron content is lower than was formerly used when greater amounts of imported ore were mixed with domestic supplies, a heavier burden must be carried by the blast-furnaces to maintain their former smelting capacity. The output of pig iron for steel-making is supplemented by scrap iron and steel, and here again stringency in shipments makes the industry dependent largely upon home supplies.

The various operations of the blast furnace were carefully studied over a long period preceding the war, and the results applied with considerable success in raising the efficiency of practically all plants. Attention was directed to the preparation and grading of ores, to the kind and quality of flux, and especially coke, to charging, to the economical application of sintering plants, and to many other factors which are associated with the successful operation of blast furnaces, notably the effects of various slags on quality and output. While much of the ground work was prepared before the war, the study of problems of the blast-furnace operation and reactions has been continued during the war to the present time.

The vital need of scrap iron and steel as a raw material in the manufacture of steel makes it essential to maintain supplies. A national drive has been in operation since the beginning of this year, by which it was hoped to supply the industry with 40,000 tons of scrap iron per week. The results of this drive is additional to normal supplies of scrap which are available through scrap merchants or which are delivered direct from factories. Much has been done during the past year or so to segregate scrap steel in particular, so that the best possible use may be made of the scrap available. Alloy steels especially, being separated according to their alloy contents, but even so-called straight-carbon steels should be scrutinised for alloy contents ; it will be found frequently that the alloy content is appreciable and is worth segregating from the carbon steel scrap, especially if the alloy present is what is regarded as a strategic mineral.

The American "General Grant" medium-sized tank proceeding at speed in the Western Desert.

gradually went out of production, yet later large quantities of basic Bessemer steel were imported into this country at a lower price than that at which basic open-hearth steel was being produced. Subsequently, however, the position was reviewed, and it was shown that the technique of the basic Bessemer process had advanced substantially and more knowledge and experience was available ; further, that although the low price of this steel was an important factor, for certain types of manufacture this kind of steel was preferred. A large plant was put into operation before the war, and although the tonnage output from the Bessemer process in this country is not comparable with the large output of the Continent, both acid and basic Bessemer converters are contributing in meeting the demand for steel.

For the main supply, reliance is placed on the basic open-hearth process, and in order to maintain a high

Tapping at open-hearth furnace at the Ford Rouge plant.

Courtesy of United Steel Companies Ltd.

Pouring steel from an acid converter.

By far the major quantity of steel produced in this country is manufactured by the open-hearth process, but all the recognised processes are operated, including the Bessemer, crucible, electric arc, and high-frequency processes. Apart from the use of the converter in steel foundries the application of this process in the manufacture of steel has been practically superseded by the open-hearth process. Acid converters continued to operate, but basic converters

production every detail of the process is being carefully studied; the war conditions have especially stimulated research activity on basic refractories. For some time prior to the outbreak of war, the Open-Hearth Refractories Joint Panel, representing the Joint Refractories Research Committee of the Iron and Steel Institute and the British Refractories Research Association, had devoted its attention chiefly to basic refractories and the data collected provided a useful standard of comparison with basic refractories now in use. Since Continental supplies of basic raw materials then in use were cut off, it will be appreciated that many problems on refractory materials have had to be solved, and much work still remains to be done.

Study of the refractories used was essential, not only to maintain the furnaces in operation as long as with the refractories formerly used, but with the idea of either increasing the working capacity of furnaces or prolonging the run before a shut-down is necessary. Production has, however, necessitated the solution of many other problems, from those associated with the making up of charges to the refining and finishing of the steel. Constant study of the whole process has been necessary, and modifications in furnace design have been incorporated in many furnaces with successful results. Further, attention has been directed to the casting-shop, with a view to improving the quality of the steel, thus, in the pouring of ingots, the ingot moulds, soaking pits and other plant have been studied and technique developed to increase the quantity of usable steel. Much has been done which helps to increase production and at the same time tends to improve the quality of the steel.

Much the same may be said of the acid open-hearth furnaces in operation, though it is probable that, due to the need for conserving alloys,

War conditions are making big demands on electric steel, whether made in arc furnaces or by means of the high-frequency process. Again, the need to conserve alloying materials has necessitated the use of minimum percentages of these elements capable of producing the properties desired, manufacture must therefore be within much smaller limits than were customary, thus the problem of control has been intensified. The production of sub-

Courtesy of English Steel Corporation, Ltd.

One of a battery of electric-arc furnaces being tapped.

stitutes for old-established steels, which retain the high-grade properties for which the older steels were noted, has necessitated the systematic application of science and technology in order that the usefulness of alloy and special steels will remain undiminished in any essential property or any specific purpose for which they are developed.

Normally, the results of research work are not readily applied, the time-lag between a development and its application in practice may be, and generally is, considerable; in the present emergency, however, efforts are concentrated on the application of developments without delay, and it is noteworthy that the various research organisations associated with the iron and steel industry have been continuously at work on problems connected with the more efficient manufacture of steel from existing plants, with the maintenance of quality, and in efforts to increase production. Much has been achieved, but the industry shows no signs of complacency, her research organisations, both private and national, are working at full pressure, while the men in the various plants are in many cases obtaining from furnaces outputs that were formerly considered to be impossible.

Courtesy of United Steel Companies Ltd.

Tapping a high-frequency furnace at one of the works of United Steel Companies, Ltd.

modifications in practice have been greater with this process, and problems not usually encountered in normal practice have caused much research, and, in addition, have called for considerable skill of the steelmaker to maintain a high quality.

Carbon Steels

By J. W. Donaldson, D.Sc.

Because of its combination of strength and workability, steel is the main engineering material; it is indispensable alike in peace and war. From a tonnage point of view the plain carbon steels easily predominate, and, under present conditions, they are especially important because of the need to conserve alloying elements. Here the author reviews some of the main types and their applications for industrial and engineering purposes, in order that suitable selection may be facilitated.

IN the selection of steel for industrial and engineering purposes the user was, under normal conditions, confronted with a large range of carbon steels whose tensile strengths increased with the carbon content, and with a large variety and ever-increasing number of alloy steels. War conditions, however, have necessitated a certain amount of rationalisation with regard to steel, with the result that a very substantial reduction has been made both in the number of steels manufactured and in the steel specifications available. This rationalisation, so far as wrought steels are concerned, has resulted in the preparation of a schedule of available carbon and alloy steels by the Technical Advisory Committee of the Special and Alloy Steels Committee of the Ministry of Supply. Emergency specification on somewhat similar lines have also been issued in the United States.

The engineer, or other user of steel, in selecting steel for a particular purpose often has to choose between using carbon or alloy steel. Carbon steels, and particularly mild steel, have many properties which commend their use in preference to alloy steels, and which ought to be taken into account before substituting alloy steels for them. Low-carbon steels have a high ductility and a well-defined yield point together with a high-damping capacity. The first two properties tend to reduce local stress concentrations, while the latter property helps to avoid dangerous vibrational stresses at critical speeds, and properties such as these deserve serious consideration before substituting alloy steels for carbon steels for certain parts. Carbon steels, however, are sometimes found to be quite unsuitable for certain purposes, and the use of alloy steels is often inevitable. This is particularly the case when corrosive conditions have to be met, or where high-temperature conditions produce scaling or cause creep to take place.

Carbon steels cannot be used under such conditions, and alloy steels are necessary. During the present emergency there has also been a decided tendency to substitute carbon steels for many parts hitherto constructed in alloy steels, not only on account of their properties but also due to economic and strategic conditions. Carbon steels are much more easily produced than alloy steels, and certain alloying elements are very difficult to obtain and their supplies have to be conserved.

In industrial and engineering work carbon steel is chiefly used in the wrought condition in the form of finished steel, comprising plates, sections, bars, sheets and tinplate ready for fabrication or as semi-finished steel comprising billets, bars, forgings and stamping, which have to be machined before fabrication. A smaller proportion of carbon steel is used for the production of castings, and a fair amount is also used for tools and machine parts.

Wrought Carbon Steels

Finished Steels.—The larger proportion of finished steel used at present is produced for the shipbuilding and engineering industries engaged in war production. A much smaller proportion, than is normally used, being utilised for structural and railway work. Plates and sections are usually manufactured of mild steel of 26 to 32 tons per sq. in. tensile strength, although steels of higher strength, 30 to 44 tons per sq. in., are also produced for certain particular purposes. For boiler construction, carbon steels containing 0·22 to 0·32% carbon and having tensile strength varying from 26 to 25 tons per sq. in. form the basis of standard boiler components such as plates, angle bars, stay bars and tubes for both fire-tube and water-tube boilers, although for pressures higher than normal, higher carbon steels are used having a tensile strength of 36 to 42 tons per sq. in. and a minimum elastic limit of 17 tons per sq. in.

Steels of the tensile strengths specified are very ductile and work easily, work such as punching and shearing in many cases being carried out cold. Such steels having carbon contents not exceeding 0·3% are also very suitable for electric arc welding, as it is generally accepted that about 0·3% carbon, with other constituents, normally represents the limit of easy weldability in carbon steels substantially free from alloy. Although the use of welding has been increasing in the fabrication of low-carbon steels during recent years, riveting of structural material still predominates, and a large tonnage of carbon steel is produced annually for the manufacture of rivets in strengths varying from 21 to 30 tons per sq. in.

Semi-finished Steels.—Large forgings in carbon steels are usually made to definite specifications ranging from 28 to 38 tons per sq. in. tensile strength. In the marine engineering and heavy engineering industries, normalised forged steel containing 0·15 to 0·2% carbon, and having a tensile strength of 28 to 32 tons per sq. in., and a minimum elongation of 30% is used for such parts as crankshafts, gear wheels and shafting; steel containing 0·25 to 0·3% carbon with a strength of 31 to 35 tons per sq. in. and an elongation of 26% for wheel rims and gear-wheel shafts and discs; and normalised, forged steel containing 0·3 to 0·35% carbon with a tensile strength of 34 to 38 tons per sq. in. and a minimum elongation of 23% for such parts as rotor shafts, wheels and drums, crankshafts, and shafting in general. Some heavy forgings containing 0·35 to 0·45% carbon are sometimes oil-hardened and tempered to give a tensile strength of 40 to 45 tons per sq. in. before being put into service, but such practice is not generally applied to carbon steel forgings, alloy steels being perferred for such treatment. For certain high-duty conditions, heavy forgings of 35 to 45 tons per sq. in. tensile strength are required, and are manufactured from carbon steel containing 0·4 to 0·45%; but their use is not general.

Bars, billets, stampings and light forgings up to 6 in. ruling section are used in all engineering industries, including automobile, aircraft, electrical engineering, marine engineering and railway and transport work. This is the class of semi-finished steel products included in the schedule prepared recently by the Technical Advisory Committee of the Aircraft and Special Steels Committee of the Ministry of Production. This schedule, B.S. 971, the object of which is to facilitate the supply of special and alloy steels for war purposes, contains 33 steel specifications, of which nine are for carbon steels and the remainder for

alloy steels. Based on this schedule the British Standards Institution has issued a war emergency schedule of wrought steels for general engineering purposes, B.S. 970, which contains specifications for 58 steels, of which 15 are for carbon steels and 43 for alloy steels.

In the various specifications in this Technical Advisory Committee (T.A.C.) Schedule, besides giving range of composition for each steel, data are given comprising proof-stress values, ultimate tensile strength, elongation per cent., and Izod-impact value for each steel. The proof-stress values quoted are given corresponding to three amounts of permanent set, 0·1%, 0·2% and 0·5%, in order to meet the variations in practice followed in different industries and by different engineers. Attention is also drawn to the influence of size and shape in determining the properties which may be obtained with the various steels. In the Table I are given a summary of the specifications for the ordinary carbon steels in the T.A.C. Schedule, and in Table II those for the special purpose carbon steels.

35 to 45 tons per sq. in. bright carbon steel suitable for automobile and aeronautical engineering parts. The composition of this steel is wide, and includes cold-drawn bars which may be adjusted to give proof-stress values up to 30 tons per sq. in. as required. The Izod value is unimportant for other than aeronautical purposes unless the part is to be subjected to bending stresses, where notches or keyways are present. T.A.C.4N is a free-machining variety of this steel intended only for nuts.

Steel T.A.C.5 is a 0·4% carbon steel suitable for motor connecting rods and crankshafts, parts requiring strength and wear resistance without specially high-impact strength, and bolts, studs, nuts, etc. The composition specified is wide enough to allow of the use of steels in general use, which are made in practice to different restricted ranges of composition. The "55" carbon steel, supplied in either the normalised or hardened and tempered condition, has little toughness as shown by impact tests. Its applications include cylinders, gears, machine-tool details, hard parts

TABLE I.—CARBON STEELS FOR BARS, BILLETS, STAMPINGS AND LIGHT FORGINGS.

T.A.C. Ref. No.	Description.	Code.	Condition.	En. Spec'n.	Composition, %.					Proof Stress, Tons/Sq. In.			Max. Stress, Tons/ Sq. In.	El. %.	Izod Ft.-Lb.
					C.	Si.	Mn.	S.	P.	0·1% Proof.	0·2% Proof.	0·5% Proof.			
T.A.C./1	Free cutting steel	—	—	En. 1	0·20 max.	0·10 max.	0·6/1·2	0·2/0·3	0·10 max.	11·5	12	12·5	28 mins.	14 mins.	—
T.A.C./2	Mild steel	A	—	—	0·15 max.	0·35 max.	0·6 max.	0·05 max.	0·05 max.	11·5	12	12·5	24/28	27 mins.	—
		B	—	En. 2	0·15/0·2 max.	0·35 max.	0·4/0·8	0·06 max.	0·06 max.	12·5	12·5	13·0	26/32	28 mins.	—
T.A.C./3	"20" to "30" Carbon steel	A	Rolled	En. 3	} 0·35 max.	0·35 max.	1·25 max.	0·05 max.	0·05 max.	11·5	12	12·5	25/35	25 mins.	—
		B	Normalised	En. 4						11·5	12	12·5	25/35	25 mins.	20 mins.
		C	O.H. & T.	En. 5						15·0	16	17	30/40	25 mins.	25 mins.
		D	Cold-drawn	En. 2	0·15/0·25 max.	0·35 max.	0·4/0·8	0·06 max.	0·06 max.	—	—	—	25·35	17 mins.	—
T.A.C./4	35/45 Bright carbon steel	—	Bright	En. 6	0·15/0·4 max.	0·35 max.	0·50/1·75 max.	0·05 max.	0·05 max.	17·5	18	18	35/45	15 mins.	20/40 mins.
T.A.C./N		—	Bright	En. 7	0·12/0·18	0·35 max.	0·5/1·75 max.	0·15 max.	0·06 max.	17·5	18	18	35/45	15 mins.	10/20 mins.
T.A.C./5	"40" Carbon steel	—	Normalised	En. 8	0·3/0·45 max.	0·35 max.	1·5 max.	0·05 max.	0·05 max.	20	20	20	35/45	20 mins.	20 mins
T.A.C./6	"55" Carbon steel	A	Normalised	En. 9	0·5/ 0·6	0·35 max.	0·4/0·75 max.	0·05 max.	0·05 max.	23	23·5	24	45 mins.	18 mins.	—
		B	O.H. & T.	En. 10						29	30	31	55 mins.	15 mins.	—
T.A.C./18	Carbon C.H. steel		Refined and Hardened	En. 32	0·18 max.	0·35 max.	0·9 max.	0·05 max.	0·05 max.	15	16	17	32 mins.	20 mins.	40 mins.
		B		En. 32	0·2 max.	0·35 max.	0·4/1·0	0·07 max.	0·07 max.	15	16	17	32 mins.	20 mins.	40 mns.

The free-cutting steel, in Table I, is used for rapid machining in automatics, and is intended for small parts such as bolts, nuts and studs for low duties. The proof-stress values shown may be appreciably lower than those given by the material in its cold-drawn and reeled condition. Values up to 20 tons per sq. in. are readily obtained, if required, in cold-finished bars, but the use of this material for highly stressed parts is not advised. The mild steels specified are for very lightly stressed parts of all descriptions. The first material, although easily machinable, is not designed specifically for rapid cutting, but is suitable where cold work, such as bending and riveting, may be necessary, while the second material is suitable for general use, but is not recommended for deep-drawing operations. Both steels can be used for case-hardening.

The third steel in Table I is a mild steel for the general engineering construction of such parts as aircraft sockets, tube-plug ends, lightly stressed brackets, levers, bolts, nuts, studs, etc. Unless required for working conditions involving bending stresses at sharp corners, its Izod value is unimportant and only maximum stress and elongation requires to be specified. It is specified in three conditions, as rolled, normalised, and oil-hardened and tempered.

T.A.C.4 is a

not required to be deeply hardened, such as rifle barrels and certain parts of small-arms breech mechanism. The usual temperatures for heat-treatment are 820° to 850° C. for normalising, 830° to 850° C. for tempering. Of the two carbon case-hardening steels specified, T.A.C.18, one contains a maximum of 0·18% carbon and the other a 0·2% maximum. Both, when suitably refined and hardened, are used for gudgeon pins, tappet rollers, light stress gears, camshafts, and all relatively lightly stressed gun and general details requiring high-wear hardness.

Of the four special purpose carbon steels in Table II, three are vehicle-spring steels for laminated and coiled springs, and the fourth an engine valve spring steel. Steels AO and AW are those most generally used for railway vehicles, and the choice of the steel depends on whether whether the spring plates are to be hardened in oil or water. In the former case steel AO is used, and in the latter steel AW. Steel A.C. is the one in general used for coil or spiral springs, and is used in the oil-hardened and tempered condition. Two main types of steel are used for aero-engine

TABLE II.—CARBON STEEL FOR SPECIAL PURPOSES.

T.A.C. Reference No.	Description.	Code.	Condition.	En. Spec'n.	Composition, %.					Maximum Stress, Tons/Sq. In.
					C.	Si.	Mn.	S.	P.	
T.A.C./25	Vehicle spring steels	A.O.	O.H. & T.	En. 42	0·75/0·90	0·4 max.	0·35/0·70	0·05 max.	0·05 max.	—
		A.W.	W.H. & T.	En. 43	0·45/0·65	0·3 max.	0·5/1·0	0·05 max.	0·05 max.	—
		A.C.	O.H. & T.	En. 44	0·90/1·20	0·3 max.	0·45/0·7	0·05 max.	0·05 max.	—
T.A.C./26	Engine valve spring steel		Hard-drawn and blued	En. 49	0·7/0·8	0·35 max.	1·0 max.	0·04 max.	0·04 max.	95-120

The Planning and Designing of Wide Strip Mills

(Specially Contributed)

Some of the principal factors which control the design and planning of strip mills are discussed. The subject is considered under two main sections: hot- and cold-rolling, and a comparison is made between various types of plants from data obtained in practice which can be regarded as a guide in making a choice for a particular service.

THE most profitable installation for the production of wide strip and sheets depends upon many factors. For very high outputs many existing plants designed and erected in the United States, for example, can be used as a guide in planning a new installation, but, to satisfy European conditions, production requirements of the smaller producer must be satisfactorily met, in regard to quality and cost, with equipment of less costly type, thus considerable simplification is necessary according to two recent reports* on the subject.

For thin strip the production process can usually be divided into two sections— the hot-rolling of the slab and the subsequent cold-rolling to the finished strip. It is the finished strip required which forms the starting point when planning a suitable plant, and its dimensions, together with the purpose for which the strip is to be used, are necessary factors. From figures of the finished sheet, the quality and dimensions of the cold strip, the hot strip and the slab can be determined. According to the reports mentioned, the finished strip is produced in widths of 3 ft. 3 in., 4 ft., 5 ft. 3 in., and in exceptional cases over 6 ft., or for tinplate in widths up to 2 ft. 8 in. Calculation of the width of strip must include scrap resulting from edge trimming. The body of the rolls should exceed the largest width of strip to be rolled by 6 in. to 8 in., but the narrowest strip should not be less than a third of the roll body.

Of special importance is the decision on how to divide the total production process into hot- and cold-rolling. Intermediate annealing of the cold material should be

* Rolling Mill Committee of the Verein Deutscher Eisenhüttenleute, Reports 169 and 171. *Stahl und Eisen*, 1942, pp. 109–114, and 257–265.

avoided for obvious reasons, and this will not always be possible. In the case of usual material a reduction up to 85% of the original thickness can be obtained economically by cold-rolling without intermediate annealing, but this figure may be exceeded in exceptional cases by using additional passes with very small reductions and high rolling speed. Some examples are given in the following figures :—

Without Intermediate Annealing.—Hot-rolled strip of 0·06 in. to 0·08 in. for finished strip of 0·04 in. thickness ; a hot-rolled strip of 0·063 in. for finished strip of 0·011 in. thickness.

With Intermediate Annealing.—A hot-rolled strip of 0·14 in. to 0·16 in. thickness may be cold-rolled to 0·04 in., annealed, and then cold-rolled the second time to a finished thickness of 0·008 in.

Consideration must be given to the adaptability of the plant for rolling additional products when the hot-rolling mill is not fully occupied in producing strip for cold-rolling to finished thicknesses. Additional products may comprise medium size or wide flat steel plates, pipe strips from lengthwise divided strips, etc. ; in such cases additional equipment is involved, such as vertical rolls for edging slabs, a cooling bed, shears, etc.

The clamping of the strip ends to produce high tension in the strip results in a considerable setting time ; a considerable length of the strip is clamped for economic reasons and results in larger reels of the rolled strip. These clamped ends should not be regarded as scrap ; they can be re-rolled, for example, to produce single sheets. Strong mechanical equipment is necessary to handle the heavy reels of strip produced. The weight of these reels, which only a few

A slab of steel entering the last of four roughing stands, in the hot mill of a 96-in. continuous-strip mill of Jones and Laughlin Steel Corporation. Another slab from the roughing stand is shown approaching the finishing train consisting of six stands of rolls, where the final hot rolling takes place.

View of six finishing stands of a 96-in. continuous-strip mill in operation at works of Republic Steel Corporation. Each stand weighs 425 tons, is 22 ft. 6 in. wide and 29 ft. above the base. From the last of these stands steel strip emerges at a speed up to 2,120 ft. per min.
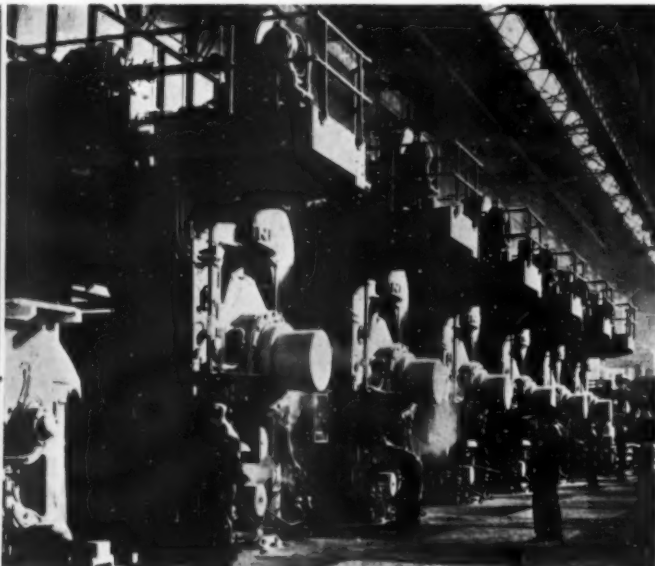
A five-stand hot-finishing strip mill operating in Great Britain.

years ago rarely exceeded 1,400 lb. for thin strip of 12 in. wide, has increased to a ton or more for thin strip, while reels of 4 tons and upwards have been handled in the case of 0·063 in. strip 50 in. wide. But the trend of development indicates modifications : strips are often rolled as accurately as possible at high rolling speeds and reeled in smaller weights, and they are subsequently welded, before pickling, into longer bands and rolled in a cold-rolling mill, where the weight of the reeled strip is of less importance than with the reversing single-rolling stand.

Production of Slabs

The thickness of the slab should be—according to a rough rule—about 40 to 50 times the thickness of the hot-rolled strip, but not less than $2\frac{1}{4}$ in. in order to obtain a thoroughly worked material and a good surface on the strip.

The width of slab does not differ greatly from the width of the strip. Edging passes are possible by means of vertical rolls, but as the width of the cogged slabs is large in comparison with their length, the rolling of the edges is more of a smoothing action than an upsetting operation.

The length of the slab depends, in addition to the length of strip, on the size of the slab-heating furnace, which must produce uniform heating throughout the slab. The width of the hearth is usually 15 ft., and rarely more than 20 ft. As these furnaces can be charged by slabs in two rows, the slabs may vary in length between 5 ft. and 18 ft. There may be several reasons for varying the length of slabs—thus, for instance, the width of the slab may be smaller than the width of the required strip, in which case the slab must be rolled across as well as lengthwise. With continuous wide-strip mills, one stand of the cogging mill is often used as a spreading stand, the body length of which may be about $11\frac{1}{3}$ ft., which limits the length of the slab. But the trend of development is to avoid the spreading stand in the strip mill and to combine it, if necessary at all, with the slabbing mill.

The cogging of ingot slabs can be effected either in a special slabbing mill or in the cogging train of the strip-rolling mill. The former method is rarely suitable for slabs of more than 5 ft. in width ; hence for wider slabs the method previously mentioned becomes necessary. With the second method the cogging train in the strip-rolling mill can only be used to rough roll the slabs by correspondingly reducing its work on the strip. Reversing stands are preferable for the cogging of ingot slabs. The slabs are cooled, the surfaces cleaned, and again heated for working in the mill, preferably in a continuous furnace.

The production of wide strip from ingot slabs in one heat by the same method as for light plates can be accepted only if no higher qualities are demanded from the wide strip than from the light plates, and especially if no subsequent cold-working is intended.

Sometimes it may be necessary to limit the rolling length due to the need for keeping the material hot ; in these cases, the installation of reel furnaces can be an excellent expedient.

Hot Rolling

When the thickness of the slab, and of the hot strip, are known, the number of passes for the continuous wide strip-rolling mill can be fixed. Experience shows that the rolling passes proper are generally 10 to 11 ; to these must be added the necessary descaling passes. Actually, the whole layout of the plant depends upon the number of passes.

The thickness of the strip is determined by the setting-up of the rolls and by the spring of the rolls caused by the decrease of the slits between the various planes of contact of the neck of the rolls, parts of the bearings, chocks, housing screws, etc., and by the elongation of the roll housings. Differences in the thickness of the rolled material depend upon the deflection of the rolls, the form of the rolls, the temperature of the rolls, the rolling temperature, and the shape of the material before it enters the rolls ; but longitudinal differences and those developed across the strip must be distinguished. The former originate mainly from temperature differences in the material. In a continuous wide-strip mill, for instance, the starting part of the strip is rolled at a higher temperature than the finishing end, if no special arrangement has been made to equalise the temperature ; hence the rolling spring will vary during one complete pass. The differences across the strip are mainly influenced by the deflection of the rolls and the shape of the material entering the rolls. With comparatively thick strip, irregular thickness causes " tongues " or " fish-tails " to develop at the end of the material. This does not arise

to the same extent with thin strip, in which the displacement across the material is reduced to a minimum. Deformations of this character must be avoided at the beginning and this necessitates a cogging mill designed on sound lines. The same consideration applies to the relation between cold-rolled and hot-rolled strip ; differences in thickness developed during the latter operation cannot be equalised during the cold-rolling process.

The shape of a groove in the rolls determines any difference in thickness across the width of the strip. The deflection of the rolls is balanced by the form of the rolls. It seems obvious that the space between the rolls should be equal throughout, but as no tension in the strip is possible in a continuous mill, the rolling of strip necessitates a good guide for the strip through the various pairs of rolls ; hence, some difference of thickness cannot be entirely avoided. When rolling in single stands, especially when reel furnaces are applied, the guide by roll groove, to some extent, is unnecessary. Skilful cooling of the rolls during the rolling process will preserve their shape. Heating of the rolls by friction losses in the bearings can be substantially reduced or avoided by the use of roller-bearings, oil-film bearings, or flood-bearings.

The importance of uniform heating of the strip is emphasised. In the continuous mill, to attain this, it is helpful to delay the strip for a short time before it enters the finishing train ; for other types of mills—e.g., the Steckel or Roechling mills, by inserting reel furnaces. It may be mentioned that simple rolling mill plants, consisting of one cogging and one finishing stand, corresponding to light-plate rolling mills, can only be used for rolling wide strips of limited lengths and of a relatively low degree of accuracy in thickness.

Cold Rolling

Cold-rolling economically can be effected with large reductions, high tension in the strip and high rolling speed, not only when differences in thickness attained in hot rolling are small, but also when these differences are about equal in various strips being rolled. Several short strips can be welded together to form one long strip if the necessary equipment is installed, but attempts at cold-rolling inadequately hot-rolled short strips by this method have usually failed. Even with the best equipment, the method of welding together the strips before cold-rolling involves many difficulties, and the use of a highly developed hot-rolling mill for producing sufficiently long strips is to be preferred.

Surfaces of high standard are only possible when the rolling of the strips is effected at a uniform temperature and by rolls possessing a hard and true surface. This can be facilitated by frequent roll changes and equipment for
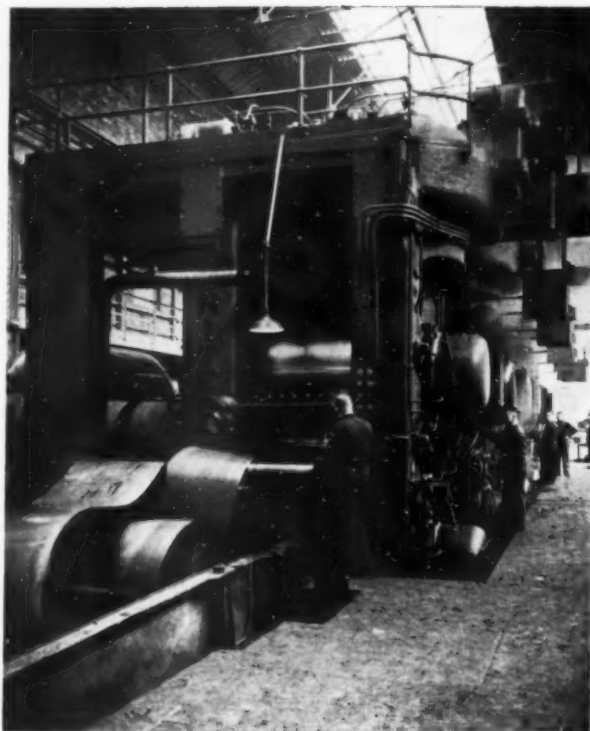
The coiling end of a five-stand cold-reduction strip mill in Great Britain.

easy and rapid changing is necessary as well as thorough descaling of the slab and hot strip. For this purpose, special descaling stands may be used, and the loose scale must be removed by water at a pressure of 850 lb. to 1,150 lb./sq. in. Finally, attention is drawn to the fact that rolling at sufficiently high and uniform temperature has a valuable influence on the mechanical properties of the finished product, and facilitates working to within small tolerances of the dimensions of the cold-rolled strip.

Comparison of Types of Mills

A general comparison of the various types of rolling mills for producing wide strip, with a view to determining which is best and most economical in a specific case, is impossible. There are so many variables to be considered that a special analysis is necessary for each case. However, the following discussion may be regarded as a guide to an investigation on the choice of a particular type, and data is given as an example of results obtained under certain working conditions, which may or may not apply to another case.

As will be noted in the accompanying table, eight types of rolling mill plants are compared, the layout and construction of which may be explained sufficiently by columns 2 and 3, with the possible exception of types 5, 6 and 7. With regard to the Steckel mill, earlier references[*] indicate that it is a type in which power is applied to the reels rather than the rolls. The mill noted in No. 5 of the table consists of a single cogging stand and a four-high reversible stand, with a reel at each side located in heating furnaces, for finishing.

The plant No. 6 comprises a single cogging stand and five stands

COMPARISON OF VARIOUS TYPES OF STRIP ROLLING MILLS.

1	2	3		4	5	6	7	8
No.	Type of Mill.	Layout and Construction.		Weight of Reels in % of No. 1.	Output per Hour in % of No. 1.	Investment Cost in % of No. 1.	Average Power Requirement in % of No. 1.	Ratio of Peak to Average Power Requirement.
		Cogging Train.	Finishing Train.					
1	Continuous type rolling mill with six finishing stands.			100	100	100	100	1·55
2	Semi-continuous rolling mill with six finishing stands.			80	70	81	—	—
3	Semi-continuous rolling mill with five finishing stands.			60 to 65	49	74	56	4·0
4	Single stands			15	14	37	11	65
5	Steckel rolling mill			100	21	48·5	18	4·0
6	Roechling rolling mill with five finishing stands.			85	53	71	40	1·8
7	Roechling rolling mill with four finishing stands.			60 to 65	35	63	—	—
8	Semi-continuous rolling mill with 4-reel furnace and five finishing stands.			70	49	74	32	2·7

* METALLURGIA, April, 1937, pp. 177–8 ; June, 1937, pp. 43–4.

as a finishing train, with three reel furnaces located between the first four stands. The strip coming from the first stand is reeled up in the first furnace, the direction of rotation of the reel being reversed as soon as the strip has been reeled up completely; hence, the strip is reeled off, leaves the first furnace, is rolled in the second stand, and enters the second furnace, where it is reeled up again. This process is continued and, after reversing the reel in the third furnace, the strip is finished in the fourth and fifth stands. The direction of rotation of the rolls always remains the same, and the strip is only in one of the first four stands at a time. Intensive tests with this type have given favourable results, especially with alloyed and stainless steel, and a still larger plant is being erected. High reduction per pass can be effected since the reel furnaces permit good uniform heating of the strip.

The furnaces, with which the plant is equipped, comprise an iron body with a refractory lining. Installed in the furnace is a fire-proof drum which is driven by a reversible motor by means of a friction coupling. Guides and supporting rolls ensure good reeling up, and on reversing the motor a good reeling off of the strip. The operator controlling the reversible motor is located above the furnace and between two stands, where he can keep the strip under observation and have the reeling well in hand. Regulation of the rolling speed is not necessary, as the strip is only in one stand at a time, and the whole equipment is relatively simple. A further advantage, in comparison with continuous mills, arises from the reversed positions of the strip, which is claimed to ensure good descaling with the use of special descaling passes or equipment. It will be noted that in the changes from stand to stand the top side of the strip in the first stand becomes the bottom side in the second stand.

The remaining data in the table may be regarded as self-explanatory.

The Solidification of Steel Castings

By D. W. Rudorff, A.Am.I.E.E , M.Inst.F.

Much-needed improvements in homogeneity of steel castings call for a better understanding of the theoretical aspects of the casting process and of the phenomena attendant to the process of structure formation. Many aspects of these processes have been studied in recent years. A more recent study of structure formation, which embraced both analytical and experimental investigations, is an important contribution to the subject, and is discussed in this article.

IT is probable that the insufficiency of the preponderantly empirical considerations followed in the making of steel castings is largely responsible for the inferiority of the cast product, as compared to the forged piece. Clearly, the much-needed improvements in homogeneity of the cast product call for a better understanding of the theoretical aspects of the process of casting as such, and of the phenomena attendant to the process of structure formation. In the latter process three important stages are generally distinguished, viz., the stages of crystallisation, of solidification, and of cooling; and the importance attached to each of these stages can hardly be over-emphasised.

Most noteworthy of the various studies of the process of casting published in recent years is that made by C. W. Briggs and R. A. Gezelius[1], but this work refers solely to the surface solidification of castings from the empirical point of view. The theoretical work of S. Saito,[2] on the temperature distribution in steel ingots, and the researches conducted by A. L. Fields,[3] on the solidification of castings, as well as the important mathematical analysis of the solidification of liquid metal by Schwarz,[4] fail to provide a solution to the solidification of complicated shapes; and this applies also to the experimental findings of B. Matuschka.[5] Thus, a general study of the problem on an analytical basis has heretofore been wanting. The importance of the exhaustive investigations, both analytical and experimental, recently made by N. Chworinoff[6] under the auspices of the Skoda works in Czecho-Slovakia cannot, therefore, be overstressed, and it is believed that a short résumé of the work of this investigator will provide considerable food for thought.

The fact that the solidification is ruled by thermal exchanges on the one hand, and by the equilibrium diagram on the other, can be used to establish an ideal picture of the phenomena occurring in the solidification and cooling of a casting. But it must not, of course, be overlooked that its value is considerably impaired by not taking into account the local heterogeneity of the material originating in the crystallisation process. In his mathematical investigation, Chworinoff assumes two infinite masses of metal which have one common boundary plane. One of the two masses is in liquid and the other in solid state. The progressive solidification of the liquid mass is expressed by a corresponding shifting of the boundary plane. Neglecting convection phenomena, the process of solidification can be mathematically expressed by the equation

$$\frac{\delta t}{\delta \tau} = a \frac{\delta^2 t}{\delta x^2}$$

in which t is the temperature decrease from the initial temperature, τ is the time in hours reckoned from the beginning of the solidification process, x is the distance of the boundary plane relative to its original position measured along a perpendicular between the planes, and a is the thermal conductivity. The temperature distribution in the mould, and in the solid as well as the liquid metal, is expressed by the same general relationship—

$$t = U + V \cdot 2/\pi \int^{x} e \frac{-x^2}{4\,a\,\tau}\,dx,$$

where U and V are constants, which are replaced by K and −K, K and D, and C and E when referring to the mould, the solid and the liquid metal respectively. Analogously, t is expressed by t_i, t_p, and t_t, and a by a_i, a_p, and a_t respectively. These equations show that the distance of an isothermal plane at every instant is of the form : $x = \text{const.} \sqrt{\tau}$ while the boundary plane of the liquid and solid phases at

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1 C. W. Briggs and R. A. Gezelius. "Studies on Solidification in Steel Castings." American Foundrymen's Assoc. Trans, vol. 41, 1934, p. 385, vol. 43, 1935, p. 274, vol. 44, 1936, p. 1.
2 S. Saito. "On the Distribution of Temperatures in Steel Ingots." Sc. Rep., Tohoku Imp. University, vol. 10, p. 305.
3 A. L. Feild. "Solidification of Steel in the Ingot Mould." Trans. Am. Soc. Steel Treat., Feb., 1927, p. 264.
4 C. Schwarz. "The Mathematical Treatment of Cooling and Solidification Process in Liquid Metal." Ar. Eisenh. Wesen, vol. 5, 1932, p. 139, 177, 186.
5 B. Matuschka. "The Laws Governing the Solidification and Crystallisation of Steel Ingots." Ar. Eisenh. Wesen, vol. 5, 1932, p. 335. Abstracted in METALLURGIA, vol. 6, 1932, p. 59.
6 N. Chworinoff. "Theory of the Solidification of Castings." Giesserei, vol. 27, p. 177, 201, 225. See also VDI Zeit, vol. 85, p. 244, and Ber. Met., 1941, p. 236.

the solidification temperature is given by $\xi \approx m\sqrt{\tau}$, where ξ is the soldified stratum; that is, the volume of soldified metal per unit of surface, and m is the thickness of metal solidified in the course of the first hour of the solidification process. The speed of solidification, therefore, is given by

$$\frac{d\xi}{d\tau} = \frac{m}{2\sqrt{\tau}}$$

which shows that at the moment of pouring the speed of solidification approaches an infinitely large value. This fact is of great importance in foundry technique.
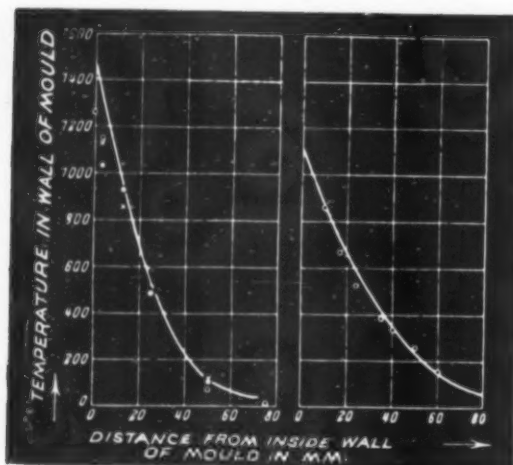

Fig. 1.—Temperature distribution curves in wall of sand mould.
Left : 15 mins. after cooling.
Right : 30 ,,   ,,   ,,

The solidification constant m can be determined by means of a graphic method established by Schwarz. But satisfactory approximate values can be obtained from the expression

$$m \approx \frac{\theta \cdot b_t \cdot 1 \cdot 15}{(W_1 + c_t u)\gamma_p}, \text{ where } b_t = \sqrt{c_t \cdot \lambda_t \cdot \gamma_t}$$

is the coefficient of " heat diffusion " of the mould, θ is the temperature of solidification of the steel diminished by the temperature of the mould, W_1 is the heat of fusion of the molten steel at the melting point, c_t is the specific heat of the liquid steel, u is the superheat of the liquid steel, and γ_p is the specific weight of the solid material. This equation shows the solidification constant to be in direct proportionality to the heat diffusion coefficient b_t of the mould ; and it also demonstrates the influence of the thermal conductivity, specific heat and specific weight of the mould material upon the solidification constant.

Where greater accuracy is required, the value found for $m\gamma$ by means of the formula given above can be used in the following expression

$$W_\epsilon \cong (W_1 + c_t\, u) \left(1 - \frac{m^2 \cdot \gamma_p \cdot c_p}{4\lambda_p} \right)$$

$$K \cong \theta - m^2 \cdot \gamma_p \cdot W_\epsilon \,/\, \cdot 2\lambda_p,$$

where the suffixes l, p and f refer to the liquid phase, solid phase, and to the mould respectively. One can thus obtain approximate values of W_ϵ and K, which, in turn, can be introduced into the theoretically accurate expression $m = K \cdot b_t \cdot 1 \cdot 158 / W_\epsilon \cdot \gamma_p$, hereby obtaining a more closely approximating value for m. Repeated use of this method will yield progressively refined values for m, but this will rarely be required. By using a mould material with a value of b_t superior to that for sand, a considerable increase in solidification speed can be achieved.

The influence of the superheat upon the magnitude of the solidification constant m is emphasised by the following

examples based on a certain set of conditions with a solidification point of 1,485° C.

$u =$	0°	30°	50°	100°	150° C
$m =$	0·058	0·044	0·036	0·017	0·000

These values indicate the great sensitivity of the factor m to excess metal temperatures ; and a superheat of 150° C. would theoretically be sufficient to prevent freezing in the casting under consideration.

Within certain limits the theoretical equation established for infinite dimensions remains applicable to the problem of solidification of a liquid mass of finite thickness in the case of sand moulds. But it should be noted that the turbulence of the liquid steel set up during the casting process tends to equalise temperatures, and this affects the validity of the
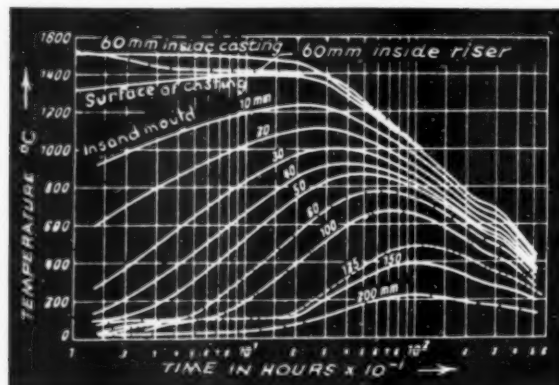
Fig. 2.—Temperature distribution obtained in the casting of a piece of 400 mm. dia. and 800 mm. long.

theoretical equations. If the steel is superheated at the moment of casting, the factor W_1, representing the heat of fusion of the liquid steel, must be replaced by the total heat content at the superheat concerned. It is interesting to note that according to Chworinoff, the time required for the solidification of a casting in a sand mould is approximately one-fourth of that experienced with an iron mould.

The Influence of the Thermal Properties of the Mould upon the Course of Solidification

At a time τ hours after casting, and at a depth x below the mould surface, the temperature t_t in the mould is given by

$$t_t = K \left(1 - 2/\sqrt{\pi} \int_0^x e - \frac{x^2}{4 \cdot a_t \cdot \tau} \cdot dx \right)$$

Thus, if the curve (t_t, x) is charted for the time τ, the corresponding curve for the end of the period τ_2 can be found by multiplying the abscissæ of the first curve by $\sqrt{\tau_2/\tau_1}$. As the quantity of heat transferred can be derived from the temperature curve by multiplying its values by $c_t \cdot \gamma_t$, the quantity of heat transferred is seen to be expressed by a parabolic curve. Mathematically, the quantity of heat transferred is expressed by $Q = c_t \cdot \gamma_t \int_0^\infty t_t \cdot dx$, where t_t is given by the aforementioned equation. One can thus write $Q = q\sqrt{\tau}$ where q is related to the factor m by the relationship $m = q / W_\epsilon \cdot \gamma_p$. In this expression γ_p is the specific weight of the steel in solidified state, W_ϵ is the total of the amount of heat released per unit of weight of the steel during its transition from superheated state to the solid state. For a thickness s, the time of solidification is given by the expression $Z = (W_\epsilon \cdot \gamma_p \cdot s / 2\,q)^2$. Assuming by way of example a temperature of 1,456° C., equivalent to a superheat of 30° C., the author of the original report obtains a mould temperature of

$$t_t = 1426 \,(1 - G)\left(\frac{x}{\sqrt{4 \cdot 0 \cdot 00145 \cdot \tau}} \right)$$
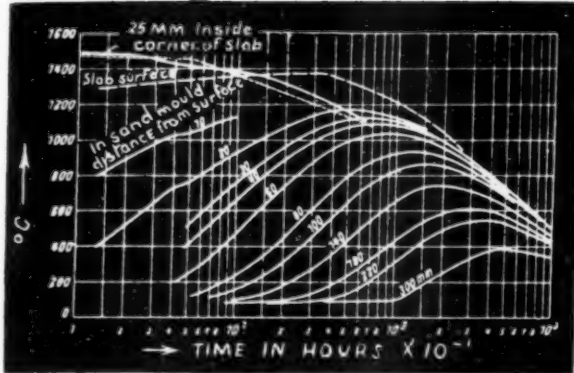
Fig. 3.—Temperature distribution in sand mould of casting of 1,800 × 2,400 × 210 mm.

Fig. 4.—Temperature distribution in the cast slab, Fig. 3.

The numerical values of t_1 for values of x ranging from 0—80 mm., obtaining after 15 mins. and 30 mins., respectively, were found to be in very good agreement with experimental data as shown in Fig. 1. In order to be able to determine the constant factors a and λ, temperature measurements were made on two pieces, one being a cylinder of 400 mm. diameter and 800 mm. length, and the other one being a slab of 1,800 × 2,400 × 210 mm.

The results of these tests are given in Figs. 2 and 3, while the temperature distribution in the slab itself is given in Fig. 4. On the whole, there is good agreement between theoretical and experimental values. Certain discrepancies are due to the fact that the factors λ, c and a are assumed to be constant in the theoretical formula, while in reality they are functions of the temperature. Also, the measured values suffer from the unavoidable errors incurred in the measurement of high temperatures. If the temperatures are charted as function of $x/\sqrt{2 \cdot \tau}$ instead of the distance x, as it is done in Fig. 5, a very satisfactory agreement between theoretical and experimental data is obtained. The report points out that a certain error in measuring the temperature is due to the exposure of the wires of the platinum-platinum-rhodium thermocouple to high temperatures. This error increases in magnitude with the temperature gradient obtaining along the thermocouple, and also with the elevation of the temperature to be measured. The physical dimensions of the protecting tube of the thermocouple constitute another source of error.

However, the discrepancies between measured and theoretically established temperatures diminish with increasing length of cooling and size of the casting. For this reason it was possible to obtain practically perfect agreement between theoretical and experimental values in the case of a casting weighing 65 tons and solidifying in 27 hours. It can be said that on the average the surface temperature of the casting in the sand mould amounts to approximately 29° C. below the mean temperature of solidification of the casting. With ordinary steel, or special steels with low alloy content, surface temperatures of the casting can be assumed to range between 1,460° and 1,430° C.

In order to be able to compute the factor q in the expression $Q = qW\tau$, the specific heat of the mould sand must be known. This enables computation of Q and henceforth of q. It has already been stated that the theoretical analysis of the solidification process is based on the assumption that at least two dimensions of the casting are infinitely large. Castings of definite dimensions must be expected to cool with greater speed than predicted by the theory since the heat is dissipated through all the walls of the mould, and not only through one wall as theoretically assumed. It, therefore, is necessary to introduce a factor which takes into account the surface area of the casting in relation to its volume. This is done by introducing the factor R = volume/surface area. In order to evaluate the influence of this factor upon the process of solidification, the time required for the solidification of castings of various shapes was determined by experiment, and the results were charted in a double-logarithmic graph with the factor R as abscissa and the solidification time as ordinate.

As Fig. 6 shows, all test results and also the data given by other workers were found to lie along a straight line, regardless of the weight of the casting as such. It could also be deduced that the length of time Z required for complete solidification is expressed by the relationship $Z = (R/m)^2$. These tests also revealed complete agreement of experimental and theoretical values of the solidification constant m.

Fig. 5.—Temperature curves $\dfrac{x}{\sqrt{2}}$ obtained from data charted in Figs. 3 and 4.
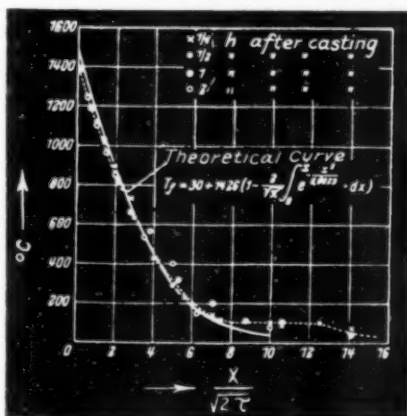
Fig. 8.—Theoretical and actual solidification zones.
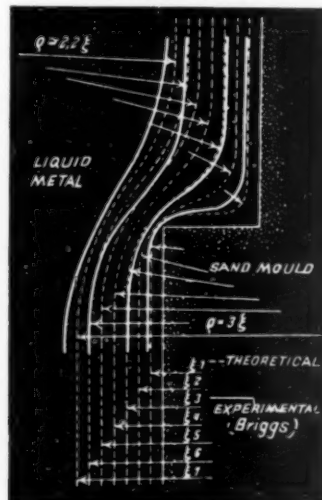
Fig. 9.—Theoretical solidification zones.
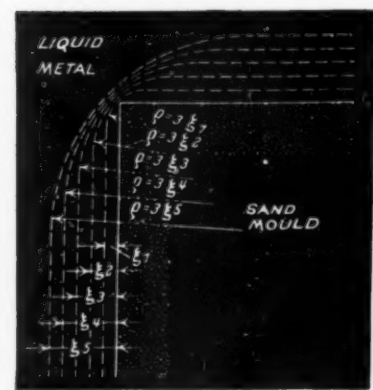
The tests also included an investigation of the temperatures prevailing at the surface of the casting, and it was found that, in the moment of casting, the surface temperature (which, theoretically, amounted to 1,457° C.) of steel castings of usual composition lies very near the end point of solidification. By increasing the carbon content it is possible to increase the amount of liquid phase in the surface skin. Or in other words, the surface skin of the casting may either be made to solidify completely in the very moment of casting, or to remain partly liquid for a long time after casting has taken place. It was actually found that in the castings investigated, the apparent skin thickness was approximately 40% greater than the amount of

thicknesses solidify quite independently of each other until the thinnest section is completely solidified. After this the rate of solidification of the other sections is accelerated. The progress of solidification towards the interior of a casting of irregular shape is shown in Fig. 8, in which both observed and theoretical solidification zones are charted. Another interesting example is reproduced in Fig. 9, which refers to a 90° corner projecting into the piece.

It has already been pointed out that temperature differences during casting, tend to produce local currents in the liquid steel. A theoretical analysis of this phenomenon is hardly practicable, but its influence upon the time required for solidification can be expressed with good approximation by the relation

$$Z' = Z \left(1 + \sqrt{\frac{t_1}{K \cdot Z} \cdot \frac{Z'}{Z}}\right)$$
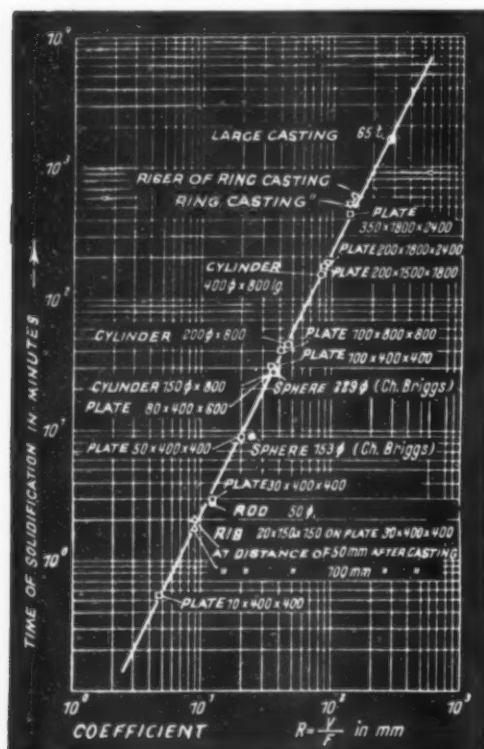
Fig. 6.—Relationship between time and solidification and coefficient R.

Fig. 7.—Distribution of solid phase as function of time and distance from surface.

metal solidified. This means that the apparently solid skin still contained 30% liquid phase.

A graphic representation of the relationship between temperature and proportion of the liquid phase in the case of a slab measuring 80 × 400 × 800 mm. is given by way of example in Fig. 7. Section (a) of this graph shows the experimentally obtained temperatures as function of the distance from the wall of the mould. Section (b) shows part of the Fe-C diagram, the arrow indicating the composition of the casting (in this case containing 0·24% C.) ; while the properties of the solid phase at varying temperatures are given by the curve shown in section (c). It is thus easy enough to chart in section (d) a family of curves indicating the amount of solid phase prevailing at varying distances from the surface at various times.

Solidification of Complicated Pieces

When examining the influence of the mould thickness upon the solidification process in the casting of complicated pieces, it was found that the thickness of the mould is practically without influence upon the solidification process as long as it is at least one-half or more the thickness of the wall thickness of the piece. The solidification of pieces with varying and abruptly changing wall thickness was experimentally investigated, and it was found that the varying

where Z' is the corrected time of solidification, and Z' is the time required for casting, while K and t_1 are defined as given above.

Bombs by Spinning

BOMB production by a new spinning method has been developed, according to a recent announcement by National Tube Co., of Pittsburgh. The method is stated to have reached a state of efficiency where it can be utilised at other plants for turning out increasing quantities of this vital war weapon. The process is being applied by the Army Ordnance Department, which plans to install suitable machines in plants of other manufacturers.

Bomb production by the spinning method is said to be speedy and effective. The process involves the use of a pre-heated steel tube, turned at a high rate of speed, and fashioned quickly and with surprising precision, into the nose and main body of a bomb by a huge arm, which swings into position and forms the revolving tube into the desired shape. Other machines, by the same method, shape the tail portion of the main bomb body. After leaving the spinning machines the bomb bodies are normalised, finished, threaded and have carrying lugs welded on. They are then painted and transported to filling plants.

The Manufacture of Wire

By a Special Contributor

Wire manufacture is a highly specialised industry, and to deal comprehensively with its many aspects would necessitate a complete volume. In this article the author reviews the procedure for steel wire from the billet stage to the finished product, dealing very briefly with rod rolling, cleaning and drawing, protective coating and stranding.

WHEN the steel melter has finished the teeming of his melt into the ladle and then run the charge into ingot moulds, the roller completes the cycle of operations by soaking and rolling the steel ingots into blooms, billets, plates, strips or sections, to be sent out to complete orders received. It is not often realised that the great care needed at this early stage bears fruit in many of the subsequent operations through which the steel-maker's finished product is subsequently passed to carry it a stage further towards its final use. Not only must the correct analysis be closely checked, but the pouring temperatures and rates of pouring for various sizes of ingot and quality of steel must be closely controlled, otherwise trouble may arise at later stages where it is difficult to correct.

In the case of billets, which are the basis of the wire industry, quite a number of important considerations in the works technique are essential if satisfactory finished wire is to be produced ; but the basis of most of them is the ensuring that the steel is as clean as possible and free from internal segregation. The ingots are carefully cropped, and the billets chipped if surface defects are visible, and liable to cause trouble in the first re-rolling.

Rod Rolling

The very great expansion which has taken place in recent years in the uses to which wire has been put calls for a very wide range in the kinds of steel made into billets for wire-rod rolling. The very low-carbon ranges are chiefly employed for electrical and magnetic purposes, and special care is needed to take them through the mechanical critical range without fracture. When it is found possible to water-quench the rods as formed, they may be used for making upholstery springs, as this saves a subsequent water-patenting operation. The medium low-carbons are usually employed for fencing purposes, as well as binding and nail wires. Higher carbon steels come into play for weight-saving, due to their increased strength, and many haulage services as well as fishing industries use specially prepared forms for cordage and warps. All sorts of wheels need spokes and tyre wires to be very carefully prepared to meet the exacting conditions enforced upon them, and the most important job of all is the preparation of the wire for springs upon which so much depends for continuous functioning. Very much depends upon the " finish " which is imparted to the product, as it may be sent out dead soft, fully hard-drawn, coated to protect it against corrosion in a variety of ways, including galvanising, plating, oil-sealed, and even enamelled for certain uses.

The comparatively leisurely methods of the original single rod continuous wire-rod mill driven by steam have long been replaced by the multiple line, electrically driven mill, and when care is taken to control temperatures properly, nor harm is done to the structure of the steel. In some few cases the all-continuous mill is found too inflexible for the demands for product, and so the combination mill has a wide variety of uses. The roughing down is continuous, and often the intermediate stages also, with staggered roll housings in the end stages, so that the break out may be made at any selected size. For the smaller rod gauges in this case the looping train is favoured, as this takes care of the stretch often found in close continuous trains, even when

slip is encouraged to alleviate this. This type of mill also enables intermediate cropping to be used to remove forked ends, which are liable to give the delay caused by a " cobble," and the flying shear is used, sometimes operated by the electric eye to minimise wastage. The coiling and cooling of the rods is important to ensure that too sudden passage through the critical range does not embrittle, nor too slow a rate of cooling divorce the carbon content, and lead to faults in the later drawing or fabricating processes.

Cleaning and Drawing

Wire drawing is not possible until the rod mill scale has been removed, and this entails a sequence of operations which can give trouble if not watched. Mechanical means have not had much success, and so chemical means are generally employed. Acid attack must be controlled by restrainers which save both acid and metal wastage, and later the removal of the occluded hydrogen, which itself causes brittleness,
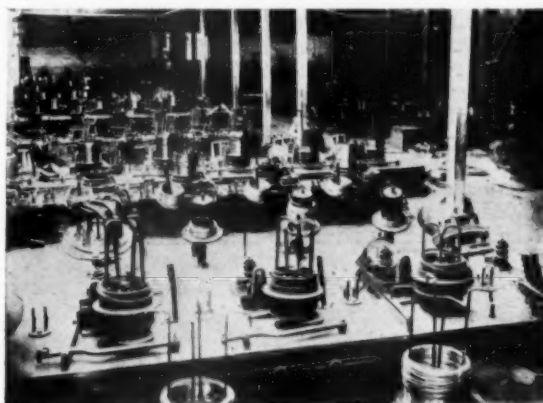
Wire-drawing benches with multiple blocks.

is more easily effected by the " ovening " or " blueing " process, which it is sometimes contended is best replaced by a lime-bath dip, and to produce the requisite coating for drawing, both are frequently employed. This coating serves to hold the lubricant, which is chiefly dried olive oil soap, but tallow may be employed when the drawing is done dry. " Wet " drawing is frequently done from a barm tub, and a copper-dipped coating also helps wet finish, and keeps it bright.

What is a prime essential is that the wire itself must not touch the draw-plate when passing through the die-hole, otherwise the surface of the wire, as well as the die, is injured. There is a true " flow " of the metal during the passage in the reduction of area, and modern practice tends to increase the percentage much beyond the traditional 20% which once constituted good holing. Untreated rod is not conducive to long holing, which gives a high final percentage reduction, and inter-annealing is resorted to in order that this low-temperature treatment may restore the power to reduce further without fracture or " cupping," which arises from internal fissuring of the wire. Other causes, such as a high-carbon core, can cause the defect ;

A large cable stranding machine.

but too late a reversing of the direction of drawing may also cause this fault to happen. The proper inclination of the die angle is another factor which must be carefully adjusted to suit the steel being drawn, and, of course, the hardest material, such as sintered carbides, is employed to hold the wire to size in place of the hammered steel dies, which were formerly replaced by cast dies, or even polished diamonds in cases where extremely small-gauge wire is wanted. Instead of the single hole draw-bench, most wire-makers favour either the continuous draw-bench with three or four holes in tandem; but for the finer sizes the same draw-bench with differential blocks and superimposed dies may be used, often with individual motor drive, in place of the older-fashioned shafting with gears. When the rod has been suitably heat-treated to give it the most suitable structure, such as full patenting to attain maximum sorbite, then the total amount of drawing may be much increased, and in this way quite high-ultimate tensile-strength values may be attained without damage to the wire, due to brittleness, as tested either by alternate bending or torsion. For this also the optimum grain size must be induced, and thereby the danger of over-drawing is avoided, as in this way the correct fibre length is produced and the interlocking structure is attained.

Protective Coating and Stranding

Bright wire always tends to become tarnished and corrosion sets in, destroying first the surface, which is important to be smooth. If it is not, and excessive draw-marks are evident, then polishing may be needed, especially in very highly stressed spring wire. Apart from oil dip and baking to form a skin, the usual protection is afforded by hot-galvanising. This lowers the stress value of the wire, but electro-galvanising does away with this reduction and uses less spelter, as sometimes the electrolyte is generated from ore without melting. The coating also is more uniform

Wire-netting machines.

and flexible, and offers very high resistance to atmospheric corrosion. This is also a great aid in stranding, either for barbed wire or fencing or into multiple-strand cables or lifting ropes. Mine-water may still attack even such a protected surface, so then efficient internal lubrication plays an important part.

The formation of large-sized cables involves considerable mechanical ingenuity, and quite elaborate machinery is employed to effect the correct stranding, and laying up of the several strands to save cutting of the wires, or their excessive twisting. Another very interesting type of machine is needed for forming the intricate shapes used to make wire-netting, and although galvanised wire is commonly used, specially prepared bare wire must be used when the netting is intended to be embedded in glass-plate to act as reinforcement.

Welding is just one more field into which wire has come as an essential unit. Specially pure steel is used in order that no inclusion or oxidisible impurities interfere with the smooth run of the added metal, melted either in the oxy-acetylene flame or by the electric-arc method. Coatings here play an important part in protecting the molten metal from absorbing oxygen or nitrogen from the atmosphere, which some advocate should be controlled, as in the hydrogen arc weld. Generally, alloy steels are not of much service in making satisfactory wire, but they are a definite advantage in welding practice since they can take care of some of the troubles liable to occur in the bare-wire method of operation.

Carbon Steels

valve springs. The first of these is a plain carbon steel, to which the properties necessary in the final condition are imported by cold-drawing with a subsequent " blueing " treatment. In order to ensure a good surface the blooms or billets used are turned or ground all over, and in addition the rods from which the wires are made are ground all over at some stage of manufacture. A special pickling test is used to ensure freedom from defects, this test being applied to small pieces cut from the ends of the coil. After cold-drawing and testing, the wire is coiled in to the spring form and the " blueing " process applied to the springs after coiling.

Cast Steel

In shipbuilding, in marine engineering, in general engineering, in automobile and aircraft work, and in railway work cast carbon steel is used for a variety of purposes. In shipbuilding, in particular, some very heavy castings are made for such parts as stems, stern frames, rudder frames, and propeller brackets. In engineering work, turbine casings, crank webs, cylinder covers, piston heads and valve details, etc., are the more important parts made in cast steel.

Steel for such castings usually contains $0 \cdot 2$ to $0 \cdot 3\%$ carbon and $0 \cdot 5$ to $0 \cdot 8\%$ manganese, and is specified to have a tensile strength of 26 to 35 tons per sq. in., with a 20% elongation in its annealed condition. For certain high-duty castings a steel containing $0 \cdot 3$ to $0 \cdot 4\%$ carbon and $0 \cdot 5$ to $0 \cdot 9\%$ manganese, and having a tensile strength of 35 to 40 tons per sq. in., and minimum elongation of 17% is used. During recent years steel castings have in some cases been displaced by parts fabricated from carbon steel plates or forgings by welding. Such fabricated parts have also been used recently to replace cast iron for bed-plates and frames in internal combustion engines, and also for many other engineering steel castings. Recent events also, which have substantially reduced supplies of tin, have necessitated the substitution of ferrous metals for non-ferrous metals. The use of cast steel in place of gun-metal has been recommended for valve bodies and other parts in high-pressure systems, and cast steel or steel fabricated by welding for parts in low-pressure systems.

Tests on the Corrosion of Buried Ferrous Metals

By J. C. Hudson, D.Sc., T. A. Banfield, Ph.D., and H. A. Holden, B.Sc.

Experiments on various irons and steels buried in clay soils for three years are described. Data have been obtained for the effects of depths of burial and other factors on the corrosion rate. It was not found possible to correlate the results of corrosion tests with any of the soil characteristics. Work is reported on a method of determining the relative corrosiveness of soils by following the change in electrical resistance of buried coils of wire due to corrosion. The interim report, from which this is abstracted, is published by the Iron and Steel Institute as Paper No. 6/1942 of the Corrosion Committee.

ALTHOUGH extensive researches on the corrosion of buried metals have been conducted in the United States by the National Bureau of Standards, and to a lesser degree in the Netherlands by the Dutch Corrosion Committee, little systematic work in this field has been undertaken in Great Britain. The subject has, however, been under consideration for some time by the Sub-Committee on Soil Corrosion of Metals of the Institution of Civil Engineers. Shortly before the outbreak of war a panel of the sub-committee was set up to prepare an extensive programme of tests on both ferrous and non-ferrous metals and alloys which had been adopted by the Committee. The execution of this programme was, however, postponed until circumstances were more propitious, but it was decided to undertake immediately certain preliminary experimental work to pave the way for the major research.

The main object of the preliminary work was to ascertain how far the conditions of exposure affect the experimental results, and thus obtain information that would ensure the avoidance of gross errors when it was found possible to proceed with the more extensive experimental programme. The effects of different depths of soil cover, of the orientation of the specimens with regard to the trench, and of the proximity of dissimilar metals, i.e., iron and zinc have been studied. In addition, the opportunity was taken to compare the resistance to corrosion of several different types of irons and steels by burying a representative selection of the materials already exposed by the Corrosion Committee in their atmosphere and marine corrosion tests, together with two cast irons. An attempt was also made to correlate corrosion with soil conditions by burying sets of specimens of three materials only in each of six trenches, dug at sites where examination of the soil had been previously carried out in connection with the laying of a new pipe-line.

The total number of specimens exposed in the six trenches was 95, of which 86 were iron or steel and 9 zinc. The wrought irons and steels were mostly in the form of " flats," with a standard size of 15 in. × 10 in. × ⅛ in. Two cast irons were tested : vertically-cast cast iron, represented by curved specimens sawn to the standard dimensions from a 15-in. pipe with an average wall thickness of 0·46 in., and sand-cast cast iron, cast individually to size, 15 in. × 10 in. by about 0·46 in. thick. Zinc specimens in the form of ⅛-in. sheet, 15 in. × 10 in., were used. Analyses and other particulars of the various materials are given in Tables I and II.

All specimens were weighed, and their dimensions recorded. Each surface was examined, particular attention being paid to scratches, the removal of rolling scale, and any surface imperfections that might subsequently be mistaken for pits. The six trenches in which the specimens were exposed were dug at points along a 14-in. main of the Mid-Wessex Water Company. They were parallel to the pipe and about 2 ft. 3 in. wide by 3 ft. 6 in. deep. Exposure was continued for three years. After exposure the specimens were cleaned preparatory to re-weighing and examination.

TABLE I.
LIST OF MATERIALS TESTED.

Material.	Number of Specimens.		Average Weight as Received. G.	Average Loss on Pickling ¹ G.
	As-Rolled or Cast.	Pickled.		
Cast Irons.				
CC, vertically-cast	12	—	8,587	—
CS, sand-cast	12	—	8,016	—
Ingot Iron.				
W	2	32	6,979	49
Wrought Irons.				
R, Swedish	2	2	7,260	106
S, Swedish, copper 0·6%	2	2	7,279	50
V, Scottish	2	2	7,220	70
Steels.				
K, chromium 1%	2	2	7,332	67
M, copper-chromium	2	2	6,814	52
XK, ordinary	2	2	6,623	67
ZK, copper 0·5%	2	2	6,697	44
Zinc.				
Zn	9	—	2,233	—

¹ The approximate total surface area of a specimen is 2·2 sq. ft. Hence, losses in weight or other data expressed in grammes per specimen may be converted into pounds per square foot of surface by dividing by 1,000.

TABLE II.
ANALYSES OF MATERIALS TESTED.

Material.	Analysis.						
	C %.	Mn %.	Si %.	P %.	S %.	Cr %.	Cu %.
Cast Irons.							
CC, vertically-cast	3·42¹	0·64	2·15	1·24	0·09	—	—
CS, sand-cast	3·22²	0·55	2·60	1·24	0·09	—	—
Ingot Iron.							
W	0·03	0·03	0·03	0·01	0·04	—	0·04
Wrought Irons.							
R, Swedish	0·03	—	0·02	0·05	0·01	—	Trace
S, Swedish, copper 0·6%	0·02	—	0·02	0·05	0·01	—	0·60
V, Scottish	0·03	0·03	0·16	0·17	0·02	—	0·12
Steels.							
K, chromium 1%	0·25	0·60	0·12	0·04	0·03	0·98	0·03
M, copper-chromium	0·27	0·89	0·15	0·04	0·03	0·60	0·50
XK, ordinary	0·21	0·59	0·10	0·04	0·04	0·07	0·03
ZK, copper 0·5	0·23	0·60	0·12	0·03	0·03	0·05	0·50
Zinc.							
Electrolytic	Zn > 99·9%						

¹ Graphitic carbon, 2·80%.   ² Graphitic carbon, 2·62%.

Discussion of Results

Although, in order to simplify the presentation of the results, average values are given in most of the Tables accompanying this paper, it should be noted that all tests were made on duplicate specimens. The percentage difference in the losses in weight of duplicates has been calculated for the 40 cases in which a direct comparison was possible, and the results are summarised in Table III. It will be seen that the average value for half this percentage difference, which corresponds approximately to the probable error of the mean value, is 8·4%. This figure is higher than the values usually observed in field corrosion tests in other media, e.g., the atmosphere and sea-water, probably because of physical heterogeneities in the soil itself, such as the presence of stones and of soil particles of different sizes. It will therefore be advisable in future tests to expose specimens in triplicate at least, in order to diminish the probable error of the mean results.

TABLE III.
REPRODUCIBILITY OF RESULTS.

Difference between Duplicates.[1] %.		Number of Cases.
Range.	Mean.	
0—2	1·4	6
2·5—4·5	3·1	7
5—7	5·8	7
7·5—9·5	8·4	8
10—12	10·9	2
12·5—14·5	13·8	2
15—17	15·8	3
17·5—19·5	18·5	3
20 and upwards	29·0	2
Mean or total	8·4	40

[1] $100(a - m)/m$, where a = loss in weight of the more-corroded specimen and m = the mean loss in weight of both specimens.

TABLE IV.
LOSSES IN WEIGHT AND DEPTH OF PITTING OF THE THREE MATERIALS BURIED IN ALL SIX TRENCHES. THREE YEARS' EXPOSURE.

Trench No.	Cast Iron.						Ingot Iron W.		
	Vertically-cast CC.			Sand-cast CS.					
	Loss in Weight. G.	Pitting. Mils.[1]		Loss in Weight. G.	Pitting. Mils.[1]		Loss in Weight. G.	Pitting. Mils.[1]	
		Maximum.	Average.		Maximum.	Average.		Maximum.	Average.
1	221	38	17	217	46	26	163	14	—
2	204	37	17	133	41	15	152	32	19
3	254	44	19	217	33	15	236	58	40
4	171	31	17	182	78	31	170	20	12
5	145	29	14	145	58	22	175	52	33
6	172	44	18	150	49	26	211	34	19
Mean	195	37	17	174	51	23	188	35	21

[1] The maximum is the deepest pit on four surfaces. The average is for the twenty deepest pits, five on each surface. A dash indicates that the value for pitting was less than 10 mils.

Specimens of ingot iron (W), vertically-cast cast iron (CC), and sand-cast cast iron (CS) were exposed at an average depth of 35 in. to the centre of the specimens (30-in. cover) in each of the six trenches. The cast irons were exposed as received from the foundry, but the ingot iron was first desealed by pickling. The mean losses in weight of the various sets of specimens are shown in Table IV. It is unnecessary to convert all the data into their equivalents in thousandths of an inch of metal per year, but it may be noted that a loss in weight of 1,000 g. per specimen roughly corresponds to the removal of a layer of metal 24 mils. (0·024 in.) thick over the whole surface. It will be seen from Table IV that the average loss in weight of all three materials was 186 g. in three years, which is equivalent to an average corrosion rate of 1·5 mils. This figure may be compared with values of 4·3 mils. per year, observed over five years' exposure to an industrial atmosphere at Sheffield, and to 4·8 mils. per year for steel immersed in sea-water at Gosport for 14 months.

Figures for the depth of the maximum pit and the average depth of the five deepest pits are given in Table IV. It will be seen that the deepest pits observed on any one specimen of each material were :

Material.	Mils after Three Years.
CC, vertically-cast cast iron	44
CS, sand-cast cast iron	78
W, ingot iron	58

[1] Pits less than 10 mils. in depth were measured on three specimens.
* Metals and Alloys.

The mean value of these maxima for the three different materials is 60 mils., or 20 mils. (0·020 in.) per year. It is interesting to note that this figure is three times greater than the mean value for the average depth of the twenty deepest pits.

The effect of the presence of rolling scale on the specimens was studied by exposing duplicate sets of eight different materials in the as-rolled and in the pickled conditions, respectively. The results are shown in Table V.

It is evident that the rolling scale has protected the specimens appreciably, since in all cases the loss in weight of the pickled specimens is greater than that of the corresponding as-rolled ones. It is known that in marine

TABLE V.
COMPARISON OF DIFFERENT MATERIALS AND EFFECT OF ROLLING SCALE. TRENCH 2.

Material.	As-Rolled.[1]			Pickled.		
	Loss in Weight. G.	Pitting. Mils.[2]		Loss in Weight. G.	Pitting. Mils.[2]	
		Maximum.	Average.		Maximum.	Average.
Cast Irons.						
CC, vertically-cast	204	27	17	—	—	—
CS, sand-cast	133	41	15	—	—	—
Ingot Iron.						
W	112	20	12	131	32	20
Wrought Irons.						
R. Swedish	104	26	15	131	32	20
S, Swedish, copper 0·6%	115	23	15	164	34	24
V, Scottish	130	30	17	149	21	14
Steels.						
K, chromium, 1%	143	31	24	162	47	26
M, copper-chromium	117	45	29	136	40	30
XK, ordinary	113	26	16	149	44	29
ZK, copper 0·5	149	38	23	172	40	26
Mean[3]	119	30	19	152	36	24

[1] As-cast in the case of the cast irons.
[2] The maximum is the deepest pit on four surfaces. The average is for the twenty deepest pits, five on each surface.
[3] Omitting the two cast irons.

corrosion the presence of rolling scale on steel tends to promote pitting. It is surprising, therefore, that the protection of the metal by the rolling scale has not been achieved at the expense of an increase in the depth of pitting. On the contrary, it is clear, from Table V, that the advantage, if any, in this respect lies with the as-rolled surfaces.

Considering the data given in Tables IV and V, it may be concluded that differencies in the composition of iron and steel, within the range of the materials tested, are of minor importance in determining the resistance of ferrous materials to general corrosion when buried in the soil. In particular, in contradistinction to atmospheric corrosion, the addition of small amounts of copper to iron and steel have no effect in retarding corrosion under these conditions ; this will be seen by comparing the figures given in Table V for Swedish wrought irons R and S, and for steels XK and ZK. These pairs of materials are of identical composition, respectively, save for their copper contents. Similar conclusions were deduced by the National Bureau of Standards from the extensive tests carried out by them in the United States.

The effect of the depth of burial was investigated by burying some pickled ingot-iron specimens at four different depths. The results of this test are shown in Table VI.

TABLE VI.
EFFECTS OF DEPTH OF BURIAL AND ORIENTATION. TRENCH 4.

Depth of Burial.[1] In.	Vertical Specimens.			Horizontal Specimens.		
	Loss in Weight. G.	Pitting. Mils.[2]		Loss in Weight. G.	Pitting. Mils.[2]	
		Maximum.	Average.		Maximum.	Average.
9	197	53	36	161	42	25
17	197	32	23	159	48	29
25	160	22	16	143	20	12
33	170	20	12	122	16	10
Mean	181	32	22	146	32	17

[1] Measured to the centre of the specimen.
[2] The maximum is the deepest pit on four surfaces. The average is for the twenty deepest pits, five on each surface.

In order to test the effect of the proximity of dissimilar materials, three sets of five specimens. each consisting of two specimens of ingot iron sandwiched between three specimens of zinc, were buried at a depth of 31 in. On considering the results, which are given in Table VII, four facts present themselves :—

(1) The loss in weight of the ingot iron has been reduced by the proximity of the zinc.

(2) The losses in weight of the specimens bears no relationship to the distance between them. It is, however, interesting to note that in the second set (6-in. spacing), where the ingot-iron specimens have lost least in weight, the zincs have lost the most.
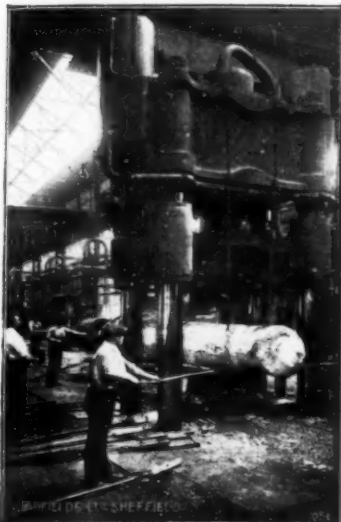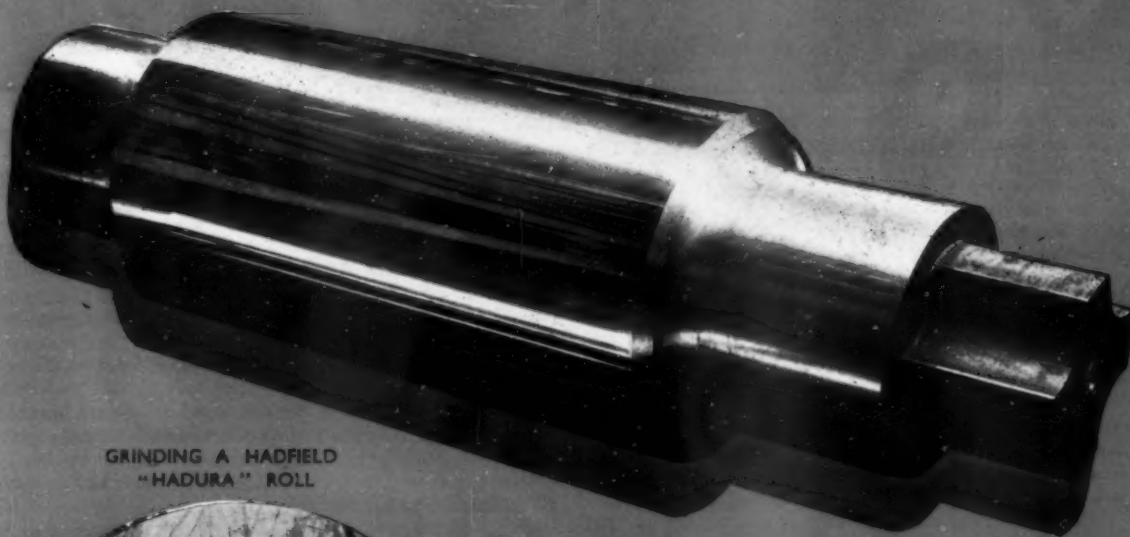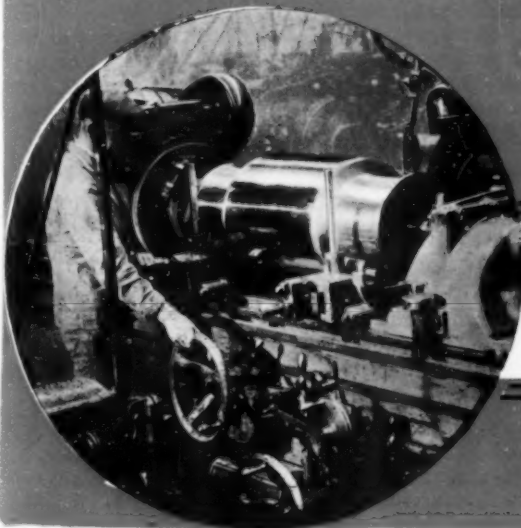
(3) The pitting of the ingot iron has been appreciably reduced by the zinc.* The specimens under discussion showed very little pitting attack after exposure, and their surfaces were good.

(4) The depth of the deepest pits are appreciably greater for zinc than for ingot iron. In both cases there is little difference between the depth of the deepest pit at 12 in. and 6 in. spacing, but 3 in. spacing there is a substantial increase.

Samples of soil were taken for examination from all six experimental trenches. The results have been compared with the values observed for the corrosion of the specimens in the different trenches, but no correlation has been found between the corrosion and any of the soil characteristics examined. Representative figures, which suffice to characterise the type of soil in which the tests were made, are given in Table VIII.

TABLE VII.
EFFECT OF PROXIMITY OF DISSIMILAR METALS. TRENCH 4.

Material.	Distance between Specimens.[1]					
	3 in.		6 in.		12 in.	
	Loss in Weight. G.	Pitting. Mils.[2] Max.	Loss in Weight. G.	Pitting. Mils.[2] Max.	Loss in Weight. G.	Pitting. Mils.[2] Max.
1. Zinc	57	24	59	20	52	16
2. Ingot iron	125	22	103	10	132	11
3. Zinc	52	25	72	18	43	13
4. Ingot iron	138	11	113	9	105	8
5. Zinc	66	22	69	19	65	20
5. Zinc	58	24	64	19	53	16
Mean, Zinc	58	24	65	19	49	16
Mean, Ingot iron	132	17	108	10	119	10

[1] In this Table the data refer to single specimens exposed alternately.
[2] The results did not justify the calculation of average values for the depth of pitting.

Electrical Resistance Tests

In this section work is reported on a method of determining the relative corrosiveness of soils by following the change in the electrical resistance of buried coils of wire, due to corrosion. Since corrosion, even in the most aggressive soils, is comparatively slow, the experimental method
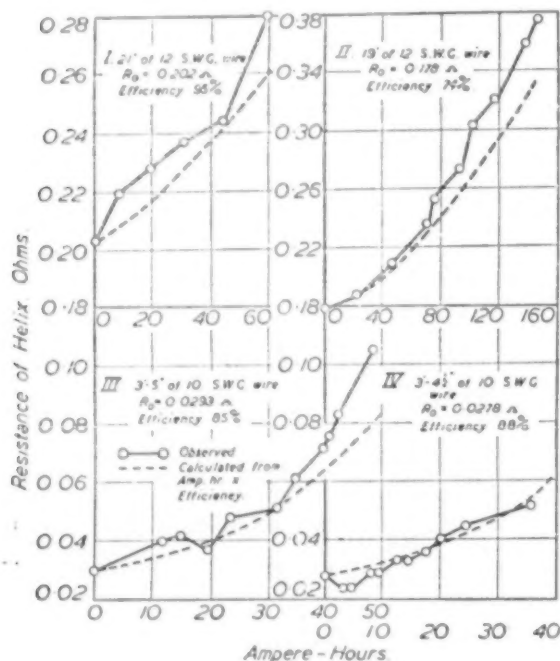

Fig. 1—Change in the resistance of a buried steel helix due to corrosion.

Pits less than 10 mils. in depth were measured on three specimens.

adopted consisted in burying a helix of mild-steel wire in the soil and corroding this artificially by electrolysis. The number of ampere-hours used for the electrolysis was determined at each stage, and at the end of the experiment the theoretical loss in weight was calculated from the total by Faraday's law. This value was compared with the observed loss in weight of the helix so as to give a figure for the efficiency of the electrolysis, which was found to range from 74 to 95%. It can be shown that the theoretical relationship between the resistance of the helix R and the number of ampere-hours Y is

$$R = W_o R_o / (W_o - eFY)$$

where R_o is the initial resistance of the specimen,
W_o is its initial weight,
e is the efficiency of electrolysis,
and F is the appropriate electrochemical factor.

Details of the experiments are given, but a glance at the experimental results shown graphically in Fig. 1 makes

TABLE VIII.
SUMMARY OF THE RESULTS OF EXAMINATIONS OF SOIL SAMPLES.

		Maximum.	Minimum.
Chemical Analysis, 1937.			
SiO_2	%	77	61
Fe_2O_3	%	13	7
Al_2O_3	%	19	6
CaO	%	2·7	0·8
MgO	%	2·0	0·4
CO_2	%	0·94	0·04
SO_3	%	0·09	Trace
SO_3, soluble	%	0·07	Trace
NaCl, soluble	%	0·29	0·16
pH		8·5	5·0
Chemical Analysis, 1940.			
Water-soluble CaO	P.p.m.	410	54
Water-soluble SO_3	P.p.m.	460	46
Saturation capacity[1]		19·8	7·8
Mechanical Analysis, 1940.			
Stones 2 mm.[2]		51·8	0·5
Coarse sand[2]	%	53·5	4·6
Fine sand[2]	%	41·4	21·7
Silt[3]		21·3	4·3
Clay[3]		39·5	11·7

[1] Milligramme equivalents of base per 100 g. of soil; if the base were all calcium, 1 milligramme equivalent would equal 20 mg. of calcium.
[2] As percentage of total air-dry soil.
[3] As percentage of oven-dry fine earth.

it clear that the essential purpose of the experiments has been achieved. It can be concluded that it is possible to follow the change in the electrical resistance of specimens buried in the soil, and that this change is a reasonably good indication of the extent to which they have corroded.

The authors conclude with suggestions for a continuation of the work. It is suggested that this should mainly take the form of developing the electrical-resistance method of testing. Experiments to date have been artifically accelerated by electrolysis. It remains to be shown that the method will respond suitably to the slower changes due to corrosion under natural conditions in the soil, and to correlate determinations made in this way with the more usual loss-in-weight tests on massive specimens.

Aluminium Casting Alloys

A VERY useful booklet, comprising some fifteen data sheets dealing with aluminium casting alloys, has been issued by the British Aluminium Co. Ltd. Each data sheet presents in a concise form information on the particular alloy that the practical man values. Not much of the information is new, but the data sheets of each material have been brought up to date, and hints are given on their anodic qualities. Brief descriptive information is given in addition to the data sheets and this is to the point.

The data sheets are concerned with standard alloys and includes 3L.5, 3L.8, 4L.11, "Y" alloy, BA.23, BA.31, BA.34, BA.37, BA.40D (L.33), BA.40J, BA.40M (D.T.D. 240 and D.T.D.245), and BA.42. For those firms who make up their own alloys, the data sheet on standard hardeners will be useful, while the last two sheets summarise British Standard Specifications and D.T.D. Specifications. Copies may be obtained from The British Aluminium Co. Ltd., Oakley Manor, Belle Vue, Shrewsbury.

Institute of British Foundrymen
Annual General Meeting in London

THE annual meeting of the Institute of British Foundrymen was held in London on June 20 when about 150 members attended. The morning was devoted to the annual business meeting, presentation of awards, the presidential address, and the Edward Williams Lecture. After luncheon four technical paper: were presented for discussion.

Major R. Miles, M.Eng., Thornaby-on-Tees, was re-elected president (1942-43), Mr. D. H. Wood was re-elected senior vice-president, and Mr. D. Sharpe (of Glasgow) was elected to the office of junior vice-president.

The considerable increase in membership recorded during the past year testifies to the value of the Institute's work which is reviewed in the annual report submitted to the meeting. This report shows that more than seventy technical meetings were arranged in more than a dozen foundry centres during the year, and indicates that the Technical Committee has proved to be an important link between the technical departments of several Ministries and the whole of the foundry industry, ferrous and non-ferrous.

Presidential Address

Major R. Miles, in his address, continued the theme of the address which he gave last year* and in it referred to the difficulties which would concern the industry in the immediate post-war period. " It will," he said, " take a long time to prepare the reconstruction on the necessary world-wide scale, especially if we are to avoid the difficulties that have always followed upheavals due to major wars. These preparations will entail planning ahead in some detail, and I am still of the opinion that we shall have to submit to a considerable degree of control for some time after hostilities are over." The importance of ensuring a reasonable standard of living for all who are willing to earn a living for themselves and families was stressed, but the main difficulty would lie in providing that all who were now engaged on war production should continue to be employed " when peace breaks out again," or otherwise catered for.

It would be necessary carefully to control production of the major necessities in relation to the total consumption assuming a minimum standard of life. This production could not, however, be readily planned by starting from the bottom with the employment of individuals, but Major Miles advanced a theory of establishing national groups whose minimum production " in pounds of this or yards of that " could be calculated. By multiplying the minimum requirements of each individual in these groups and adding together the totals of each group, the grand minimum total consumption would be obtained. Since production of the major necessities could exceed the consumption, the required production would have to be distributed *pro rata* to the consumption, bearing in mind geographical and other considerations. Even then a large balance of unexpected effort would remain, and this could be applied with considerably less control to (1) less necessary consumption of goods, (2) public works, and (3) luxuries. Major Miles particularly stressed his belief that the primary absorption of man-power after the war must be in the production of consumption goods and that difficulties would be very considerably reduced " if the ' grab-all ' spirit were eliminated and if the stronger national groups would act as elder brothers in the family."

" There is no ready solution ' just around the corner.' The man who prescribes a panacea for our social ills, is a quack " declared the president. So long as one type of person climbs Snowdon while others come down the switch-back at Blackpool there would be class distinctions. " Capitalistic system " was another term often used erroneously. Capital was most commonly the bridge built between the time of production and the time of consumption— " the tea you had in your cup this morning was grown by a coolie who required paying a year or two ago ; you only paid for your tea last week." Whether the State or the individual controlled the use of capital was of secondary importance. Modern production demanded increasingly large units and frequently only the State could supply the necessary capital, but who ever employed capital there must be some return on the whole if material progress was to be made.

All these problems were not too complicated to be solved, but any sweeping claims for any particular system should be suspected. Transitional difficulties would not, he thought, impair his main theory of working to an approximate calculation of the minimum major needs, at any rate amongst those national groups who would " play." " Complete solutions," he concluded, " will never be within our grasp, but we must all work with good will . . . to make the world, and especially our own immediate world, happier and better as a result of our efforts."

Presentation of Awards

THE E. J. FOX GOLD MEDAL 1942, was awarded to Mr. P. H. Wilson, assistant managing director (Technical) of the Stanton Ironworks Co. Ltd., for his work in the development of the centrifugal casting process for the production of cast iron pipe. The presentation was made by Mr. E. J. Fox who has recently retired from the managing directorship of the Stanton Ironworks Co. Ltd. In his reply, Mr. P. H. Wilson made a most interesting review of the technical development of the process since the beginning of the century.

THE OLIVER STUBBS GOLD MEDAL 1942, was awarded to Mr. S. H. Russell, past president and honorary treasurer, in acknowledgment of the educational work which he has undertaken for many years as chairman of the City and Guilds of London Institute Advisory Committee, the contributions which he has made to the discussions on papers at branch meetings, his work as honorary treasurer of the Institute, and his chairmanship of the Organisation Committee responsible for drafting the proposed new rules. Mr. H. S. Russell is managing director of S. Russell & Sons, Ltd., Leicester.

THE MERITORIOUS SERVICES MEDAL 1942, was awarded to Mr. S. W. Wise in recognition of the considerable service which he has rendered to the Institute during thirty years of membership. Mr. Wise has been registrar and a vice-president of the Newcastle branch · he was an examiner for the John Surtees Memorial examinations, and for the past sixteen years has been honorary secretary of the West Riding of Yorkshire branch.

Edward Williams Lecture

The fifth Edward Williams lecture entitled " Foundry Teamwork " which had been prepared by Dr. H. W. Gillett, editorial director of *Metals and Alloys*, and chief technical adviser to the Battelle Memorial Institute, Columbus, Ohio, U.S.A., was presented on behalf of the author by Mr. J. G. Pearce, M.Sc., M.I.Mech.E., M.I.E.E. F.Inst.P., director of the British Cast Iron Research Association.

In the lecture, Dr. Gillett referred to the Presidental address given by Mr. C. E. Williams (in whose honour the lecture was established) in 1933. Therein Mr. Williams had referred to the team spirit which the Institute exhibits and fosters not only in this country but abroad. The lecturer drew attention to the very considerable volume of

academic and industrial research work published in the technical press and the proceedings of the learned societies which was neither assimilated not utilised by industry. In addition there are all " the little tricks and kinks of saving of labour and materials and for improvement of quality, that have been worked out in individual plants but never recorded in technical literature."

War-time conditions are conducive to co-operation between producers of any product since the Government is largely the sole purchaser. In peace-time, however, there is often a reluctance to pass on information because of competition between suppliers. In the case of the foundry industry severe competition is already being encountered from welding, forging, and even powder metallurgy, whilst within the industry itself aluminium and magnesium castings are finding an ever widening field of application. All this is good from the point of view of the general public who will benefit from better and cheaper materials, but it is not satisfactory to those engaged in making the " old-line foundry products." " Under such pressure teamwork, even among active competitors, to preserve their industry as well as the individuals therein, is favoured."

Dr. Gillet then reviewed the history and activities of many of the American metallurgical societies, stressing the great importance of the " practical " contribution to discussions, and the desirability of establishing, or working within small, specialist groups to examine and provide information on the particular problems. Although these small groups were to be preferred to nation-wide organisations (unless the latter had proper branches organised in foundry centres, as had the American Foundrymen's Association) it was essential to have able co-ordinators available who, by personal contact, were able to ensure the proper utilisation of information made available through group discussion.

With the lecture a technical supplement was submitted on " Cupola blast control " by S. A. Herres (formerly a Research Associate, Battelle Memorial Institute, now Lieut. Engineering Corps, U.S. Army) and C. H. Lorig (supervisor, Foundry Department, Battelle Memorial Institute). In this section the authors emphasise that every foundry interested in maintaining quality and economy on cupola operation should base air supply on a constant weight of oxygen. For this purpose control equipment for making temperature-pressure corrections is important and will prove an economical investment, especially since the initial cost is nominal. The application of such equipment is discussed, and appendices detail methods of compensation for humidity changes which should be made when a critical type of casting is produced.

Technical Session

Several papers and reports were subsequently presented and discussed. The papers dealt with aspects of a ferrous character and embraced the production of light steel castcastings ; the manufacture, control, and applications of a malleable cast iron known as ArmaSteel ; and of high-duty cast iron. The reports were concerned with non-ferrous metal and contain a wealth of information and data designed to conserve the use of tin for those in which its use is essential. These papers and reports are briefly reviewed under their respective headings.

The Production of Uniform Steel for a Light Castings Foundry

A DESCRIPTION of the routine practice employed in a light castings foundry, to produce liquid steel at periods when it is most required, is given by C. H. Kain and L. W. Sanders. The foundry in which this practice operates is producing 95 to 100 tons of finished carbon-steel castings weekly, and although this may be regarded as a modest tonnage, it is noteworthy that this tonnage is just double the output for which the plant was originally designed. Since the castings are made almost entirely in green sand, the floor space must be utilised to the utmost for the production of moulds ; especially will this be appreciated when it is realised that a typical week's output is made up of over 5,000 castings with an average weight of 38 lb.

This output can only be maintained by careful planning and working to a pre-determined programme. The planning is based on the number of moulds which can be produced in a given time by the equipment installed. The core output is adjusted to suit this, the moulds finished, cored up and closed as they are made. It is then necessary to have liquid steel available to cast into the moulds in order that the floor may be cleared for the repetition of the cycle. The authors described the scheme adopted to standardise steel production so that each batch of moulds may be cast when ready.

Two processes are in use, the basic electric and the Tropenas. The combination is stated to have two great advantages :—

(1) The basic electric can use a wide range of scrap and produce a low-phosphorus/low-sulphur metal, the re-melt from which can be used in conjunction with West Coast hæmatite in the Tropenas to produce steel with a phosphorus and sulphur content comparable with electric steel.

(2) The electric furnace can be adjusted to produce a heat of steel at precise intervals (of 4 hours in this case), day and night, whilst the Tropenas can produce heats at high speed during the peak casting period, which in most foundries is during the afternoon.

As there are so few castings of large weight, it is not possible to open up the nozzle on a mould of several hundredweights capacity, and, if it were possible, it would be undesirable as the standard steel is at much too high a temperature for heavy castings. Hand-shanking from both types of furnaces is practised to a great extent, small moulds being poured in this manner without difficulty. Table I shows the time-table which is worked in the foundry under consideration and each process is considered in three phases, as shown in Table II.

TABLE I.
TAPPING TIMES.

Electric Furnaces.		Converter.	
A.	B.		
2 a.m.	—	1-30 p.m.	Soft.
6 a.m.	—	2-15 p.m.	Hard.
—	9 a.m.	2-45 p.m.	Soft.
10 a.m.	—	3-15 p.m.	Soft.
—	1 p.m.	4-0 p.m.	Hard.
2 p.m.	—	4-30 p.m.	Soft.
6 p.m.	5 p.m.	5-15 p.m.	Soft. Delayed to permit 5 p.m. heat from B.
10 p.m.	—		—

TABLE II.
DIVISION OF PROCESSES.

Electric Furnace.	Tropenas Converter.
1. Charging and melting.	Melting and desulphurising.
2. Oxidising (converting and slagging off)	Blowing (converting).
3. Reducing (refining) finishing and tapping.	Finishing and tapping.

Table III shows the standard time-table which is aimed for both processes.

The electric furnaces in use are the Electrometals type with two top electrodes and a conducting hearth. They are rectangular in shape with nut and screw operated tilting and elevating gear. The maximum capacity is 50 cwt., and charging is entirely by hand. The nominal rating is 650 k.v.a. The basis of the process lies in standardisation of the charges, a controlled boil and speed in working.

TABLE III.

Electric Furnace.	Time.	Converter.	Time.
	a.m.		p.m.
Previous tap complete	9–0	End of heating period	12–45
Fettling furnace complete	9–15	Fettling complete	12–57
Charging complete..........	9–45	Charging complete	1–9
Melting complete	11–45	Blowing complete..........	1–22
Slagging off complete	11–50	Finishing and recarburising	1–25
	p.m.		
Finishing complete	12–50	Ready to tap	1–28
Ready to tap	12–55	Tap complete	1–30
Tap complete	1–0		

The converter equipment comprises one 20-cwt. Tropenas converter with a positive Rootes blower to furnish air. One balanced-blast cupola, 27 in. diameter, capable of melting 3 tons of iron per hour, and one 2-ton ladle for receiving the cupola iron for transfer to the converter ; one lip-pouring ladle from which steel is hand-shanked, and several bottom-pouring ladles, all of which are pre-heated by gas burners. The vessel is nominally of 1-ton capacity, but the first charge is never less than 27 cwt., and this increases as the lining wears. The average life of the lining is 70 blows. Practice with the converter is based on a standardised charge, uniform vessel temperature and controlled blowing conditions. Desulphurisation of the cupola metal is effected by adding to the receiving ladle 1 lb. of sodium carbonate to 1 cwt. of metal.

TABLE IV.
ELECTRIC STEEL TAPPING TEMPERATURES AND TIMES.

Electric Furnace.	Shanking Heats.	Bottom Pouring Heats.
	°C.	°C.
Tapping temperature	1,650	1,580
Temperature—first pour	1,600	1,560
Temperature—last pour	1,560	1,530
Time pouring................................	25 mins.	20 mins.
Number of moulds	80	67
Weight of metal cast	47 cwts.	45 cwts.

The tapping temperature for shanking steel from the electric furnaces is approximately 1,650° C., and for direct-pour heats 1,580° C. Details of pouring times and temperatures are given in Table IV.

The tapping temperature of the converter steel compares favourably with that of the electric furnace. Shank heats are tapped at approximately 1,660° C., and bottom pouring heats at 1,600° C. Table V gives details of pouring temperatures and times.

TABLE V.
CONVERTER STEEL POURING TEMPERATURES AND TIMES.

Tropenas Converter.	Shanking Heats.	Bottom Pouring Heats.
	°C.	°C.
Tapping temperature	1,660	1,600
Temperature—first pour	1,630	1,560
Temperature—last pour......................	1,575	1,530
Time pouring	25 mins.	20 mins.
Number of moulds	88	75
Weight of metal cast	32 cwts.	30 cwts.

The chemical composition and physical properties of the steels produced by both processes, after normalising from 900°/920° C., are detailed in Table VI.

TABLE VI.
PROPERTIES OF STEEL MADE BY THE TWO PROCESSES.

Heat No.	Composition, %.					Physical Properties.			
	C.	Si.	Mn.	S.	P.	Y.P. Tons per sq. in.	U.S. Tons per sq. in.	El. %.	R.A. %.
			Basic	Electric	Furnace.				
Co. 10970	0·20	0·25	0·85	0·020	0·015	20·8	32·75	39	40
B. 3448	0·41	0·33	1·10	0·020	0·015	24·75	41·55	25	45
			Tropenas	Converter.					
F. 9261	0·18	0·22	0·85	0·032	0·037	17·20	32·00	36	56
F. 8349	0·33	0·35	1·10	0·032	0·037	20·00	35·55	24	30

ArmaSteel : Its Manufacture, Control and Application

THIS paper, by Carl F. Joseph, was presented as the exchange paper of the American Foundrymen's Association, it deals with a type of malleable cast iron which carries the trade name ArmaSteel. This metal, in some cases, is referred to as a graphitic steel, since the matrix closely resembles that of a spheroidised steel. According to the author its development dates back some twenty years, but the earlier researches were given little encouragement by engineers, and it has only been during the past five years that any real progress has been made in production of the product.

ArmaSteel is made from white cast iron of the following composition : 2·65% carbon, 1·35% silicon, 0·40% manganese, 0·13% sulphur, 0·05% phosphorus. The metal is melted in a cupola and refined and superheated in an electric arc furnace. Very close chemical control is followed through from the raw materials used to the finished product. Rigid metallurgical control is maintained on all operations. The combined carbon in the matrix gives to the metal properties which compare favourably with those of forgings in the low-carbon steel range.

The heat-treatment of the white iron casting is one of the most important operations. The surface structure must be free from decarburisation, therefore close control of furnace atmosphere is necessary. Radiant-tube furnaces, fired with natural gas, are used for heat-treating. The castings are heated to 954° C. and held at this temperature long enough to remove all massive carbide, usually about 15 hours. The castings are then cooled to 870° C., and air- or oil-quenched. This is followed by a tempering treatment to improve machinability and control physical properties. The time and temperature vary with the design of the casting and the Brinell hardness requirements. A tempering temperature of 675° C. for 4 to 6 hours will produce castings of approximately 197 to 241 Brinell, and for 6 to 8 hours 163 to 207 Brinell hardness.

Control of uniformity of the product is based on adequate statistical information regarding the product itself, and the variables of its manufacture. To this end statistical systems are employed to record melting and raw material variations, and to correlate these factors with quality and uniformity. By a study of the records the metallurgical practice in the plant will fall into a narrower groove of smaller deviations, with the ultimate result of lower rejections and higher quality. The author gives considerable attention to the various aspects of control in the production of ArmaSteel products.

Many desirable properties claimed for this material make it of outstanding interest in the ferrous field. In general, its machinability is from 10 to 30% better than steel forgings of the same Brinell hardness. Excellent damping characteristics are demonstrated in many parts, such as camshafts produced from the metal. It has a high-yield ratio, especially when a Brinell hardness of 200 or over is desired. Many installations incorporate it in place of bronze bushings, and its excellent non-seizing properties in metal-to-metal wear are recognised. Crankshaft tests have proved the high-fatigue life of this metal. One of its most valuable properties is its ready response to localised hardening ; camshafts, for instance, are readily flame-hardened. Flame-hardening and induction-hardening are successfully applied to the cams on camshafts, shifter yokes and gears, etc., made in ArmaSteel. This surface hardening produces maximum wear resistance.

The Substituting of High-duty Grey Iron for Steel Castings

INCREASE in the use of high-duty grey-iron castings has been progressively accelerated by war conditions, and they present extending potentialities for post-war developments. Great progress has been made in the production of high-duty grey iron in the last decade, and J. Blakiston directed particular attention to the manner in which engineers have taken advantage of the developments. The first part of his paper is devoted to concrete examples of high-duty grey iron displacing cast steel.

High-speed Diesel and petrol engines are fitted with grey-iron crankshafts as a matter of course. Before Ford fitted his mis-named cast iron (actually hyper-eutectoid cast steel) crankshafts to his standard cars many American manufacturers had been using high-duty grey-iron crankshafts for refrigerators and such-like machinery, but kept the matter secret as they were afraid of public prejudice against cast iron.

While the foundry has developed the potentialities of modern irons, engineering advancement has also been effected in several ways, such as increased power and stability of modern machine tools, enabling heavier cuts to be taken economically on tougher materials ; improvement in cutting-tool properties by the introduction of tungsten carbide, which renders castings machinable more or less independent of hardness ; and improvement in engineering finish and limits, particularly by precision grinding, which reduces breakages caused by misalignments and also hammer action by maintenance of correct bearing clearances.

Typical examples given of high-duty grey iron displacing steel castings or forgings include a 45 ft. by 1 ft. 6 in. solid boring bar ; a large boring lathe head, the hollow spindle of which is of 19 to 20 tons tensile iron, and weighed approximately 6 tons in the rough state ; a milling machine spindle ; a horizontal boring machine main spindle-neck bearing, while the main traverse rack and column rotating rack, formerly made in 0·4% carbon steel, are made in high-tensile grey iron having a tensile strength of 25 tons. The main table rack of a modern heavy planing machine, formerly made in steel, and also the tool clapper boxes, are now made in high-duty cast iron. Modern grey irons readily meet the arduous services required, and take the shock of high-speed reversals without fear of failure. Many more examples are given by the author, but the whole of those chosen indicate only a few from an enormous field of successful applications.

In the second part the author dealt with methods of convincing engineers with the potentialities of high-duty grey-iron castings ; his views were directed more particularly to the small-scale ironfounder contemplating the manufacture of these castings, to whom he gives much valuable information from the production point of view. With the practical man, and even certain members on the administration staffs, tensile test and figures cut no ice, and Mr. Blakiston gives a series of tests which are simple, and which have assisted in influencing certain sections of the engineering community respecting the possibilities of high-duty irons.

Test weight.
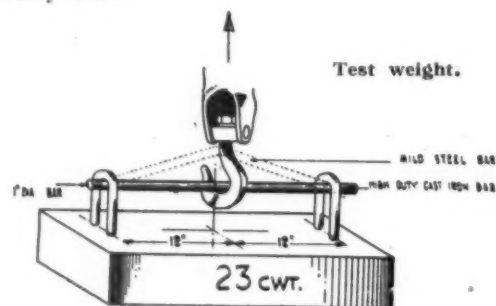
The small-scale ironfounder cannot be expected to own a complicated modern testing machine, but a simple device is illustrated by means of which a test can made which not only indicates a satisfactory iron but tends to impress prospective users with the results. The apparatus consists of a block of cast iron weighing 23 cwt., with two staples cast in 24-in. apart. If a 1-in. diameter cast-iron test-bar is placed between these staples, which has a tensile strength of 23 tons or upwards, it should be possible to lift the block from the centre by means of a crane-hook. Should a 1-in. diameter mild-steel bar be substituted for the cast-iron bar, it will be found that the block cannot be lifted, as the yield-point of the mild steel is considerably below that of the weight of the block. Several other practical tests are described which indicate the possibilities of high-duty grey iron for many purposes.

Reports on Low-Tin and Tin-Free Bronzes and Brasses

IN consequence of the present need for economy in the consumption of tin, the Non-Ferrous Sub-Committee of the Technical Committee has had under consideration the use in the foundry of alloys free from tin or containing lower percentages of tin as substitutes for Admiralty gunmetal and similar bronzes. The British Standards Institution has also given consideration to the same matter, and has drawn up War Emergency Specifications for two additional gunmetals, two grades of cast brass, a silicon bronze, and an aluminium bronze. It is proposed by the British Standards Institution, and by the Government Departments concerned, that for the duration of the war the use of Admiralty gunmetal of the 88–10–2 type should be severely restricted, that leaded gunmetal of the 87–9–3–1 type should not be used, and that the alternative alloys, prepared as far as possible from scrap, should be substituted.

One of the major points raised during the Sub-Committee's discussions concerned the foundry characteristics of silicon bronzes. It was felt that, while good-quality castings could readily be produced in these alloys by experienced foundries some difficulty might be met by those not accustomed to their use. A panel was therefore formed to provide suitable guidance on foundry technique, and a report of this panel is in Part I. A comprehensive review of the properties and applications of the low-tin bronzes and brasses is given in Part II by Mr. F. Hudson, while in Part III Mr. J. Arnott and Mr. E. J. L. Howard give the results of practical tests on the foundry characteristics of the low-copper-content brass covered by B.S.S. 1028. Brief reference to these reports is made in the following notes.

Part I.—Silicon Bronzes as Casting Alloys

B.S. War Emergency Specification 1030 gives the following limits of composition :—

Silicon	1·50 to 5·00%
Manganese	1·50% max.
Zinc	5·00 ,,
Iron	2·50 ,,
Total element other than copper and those specified	0·50 ,,
Copper	Remainder.

The mechanical properties called for in the specification for either separately cast or cast-on test-bars are : ultimate tensile stress, 20 tons/sq. in minimum ; elongation tensile stress, 15% minimum.

The silicon bronzes are capable of giving close grain, homogeneous castings of high strength, toughness, good resistance to corrosion, and suitability for pressure work. When molten they are very fluid, producing sharp and well-defined castings from sand moulds. They can also be cast by the centrifugal process and in chilled moulds.

They may be melted without difficulty in pit fires or tilting furnaces of the coke-, oil- or gas-fired types. Melting should be carried out as quickly as possible, exposure to the furnace atmosphere being kept to a minimum. The melt may be kept well covered with a gasless flux, such as ordinary bottle glass, cryolite or sal-ammoniac. In cases where the liquid slag is very fluid, a sprinkling of dry silica sand may be used to thicken it so that it may readily be skimmed prior to casting.

The molten metal should not be allowed to remain in the furnace too long after the casting temperature has been attained. Excessive stirring or puddling during melting should be avoided, as this is not only unnecessary but tends

bronzes providing the above points receive due attention. Where the design of the castings is such that adequate feeding metal cannot be introduced, chilling may be resorted to with advantage.

As regards moulding and core-making sands, silicon bronzes cast well with the usual types of sand used for other non-ferrous alloys as gunmetal, phosphor bronze and manganese bronze, and ordinary facings as lithite and plumbago give good results when used with green sand or dry sand moulds. Care should be taken, however, to ensure ample permeability, as impermeability produces skin porosity. Silicon-bronze castings are clean when removed from either green or dry sand moulds, providing an unduly

TABLE I.—MECHANICAL PROPERTIES OF LOW-TIN CONTENT GUNMETALS AND CAST BRASSES IN COMPARISON WITH 88-10-2 GUNMETAL.

Properties.	Gunmetal.				Cast Brass.	
	88–10–2. Sn 9·5/10·5% Zn 1·5/2·5% Pb 0·50 max. Ni 1·00 max. Imp. 0·15 max. Cu balance. —	88–8–4. Sn 7·5/8·5% Zn 3·5/4·5% Pb 0·50 max. Ni 1·00 max. Imp. 0·15 max. Cu balance. —	86–7–5–2. Sn 6·0/8·0% Zn 4·0/6·0% Pb 1·0/3·0% Ni 1·00 max. Imp. 0·50 max. Cu balance. —	85–5–5–5. Sn 4·0/6·0% Zn 4·0/6·0% Pb 4·0/6·0% Ni 1·00 max. Imp. 0·50 max. Cu balance. —	Type A. Sn 2·00% max. Zn balance. Pb 1·0/4·0% Ni 1·00 max. Fe 0·75 max. Al 0·01 max. Imp. 0·50 max. Cu 70·0/80·0%	Type B. Sn 2·00% max. Zn balance. Pb 1·0/4·0% Ni 1·0% max. Fe 0·75% max. Al 0·25 max. Imp. 0·50 max. Cu 62·0/70·0%
Y.P., tons/sq. in.	8—10	8—10	7—9	6—8	4—6	5—7
M.S., tons/sq. in.	16—20	16—20	14—16	12—16	11—15	14—18
Elongation % in 2 in.	10—30	10—30	12—30	15—35	20—40	15—35
Izod impact, ft.-lb.	7—17	7—17	7—17	6—12	10—20	—
Brinell hardness	65—80	65—80	60—70	55—65	40—60	45—65
Diamond pyramid hardness*	70—100	70—100	70—80	60—70	—	—
Compressive strength tons/sq.i n., 0·001 in. deflection	6—8	5—8	5—6	4—5	3—4	3½—4½
Modulus of elasticity, lb. by 10⁶	12—14	12—14	12—14	11—12	11—14	12—14

* Diamond-hardness readings on cast material are likely to be variable, and this method is therefore not recommended for control purposes.

to disturb the protecting cover, and may cause gas pockets in castings as a result of contamination of the metal by furnace gases. The metal should be stirred with a graphite stirrer or a coated iron rod. Care should be taken not to overheat the alloy.

Scrap can be added to furnace charges in the usual amounts without detriment to the castings produced. Great care should, however, be observed that no damp or oily scrap is melted in that condition. Segregation of scrap for silicon bronzes is of particular importance in reference to tin and lead contamination, which should be avoided. The average casting temperature is in the neighbourhood of 1,130° C., this being modified as required to suit thick or thin sections. The alloy has considerable fluidity, therefore thin sections can be successfully cast.

The characteristic of all silicon bronzes is their short freezing range, approximately 50° C., and shrinkage therefore takes place at a greater speed than in the gunmetals. This necessitates special attention to the feed requirements, heads and runners of generous size being required. Various moulding methods may be employed for casting silicon

high casting temperature is avoided. Castings removed from the moulds while red-hot will not scale unduly in the atmosphere.

Cast silicon bronzes are readily weldable by the auto-genous acetylene or arc methods, and castings containing sand-holes or blow-holes can be salvaged readily by welding these defects. When oxy-acetylene welding, a distinctly oxidising flame should be employed, rod or wire of the same composition being employed. A suitable flux is composed of 9 parts fused borax and 1 part sodium fluoride.

The above general data refer particularly to P.M.G., marketed by Vickers-Armstrongs, Ltd., and Everdur, marketed by I.C.I. (Metals), Ltd. As these two alloys were developed separately, certain differences may arise in practice, and further details of their individual properties are given in the report.

Part II.—Properties of Sand-Cast Low-Tin Content Gunmetals and Brasses

It is not possible to eliminate the higher tin-content alloys entirely from engineering applications. For certain

TABLE II.—MECHANICAL PROPERTIES OF GUNMETAL AT ELEVATED TEMPERATURE.

Temperature.		Sn 12·25 Zn 1·46 Pb 0·01 Fe 0·01 Cu 86·21 †			Sn 10·0 Zn 2·0 Ca 88·0 *			Sn 10·11 Zn 1·63 Pb 0·36 Cu 87·84 ‡			Sn 5·85 Zn 5·77 Pb 2·06 Cu 86·24 †			Sn 5·99 Zn 5·10 Pb 2·33 Cu 86·28 †			Sn 6·22 Zn 4·61 Pb 1·83 Cu 87·11 †					Sn 5·24 Zn 5·48 Pb 5·33 Cu 83·37 *	
°F.	°C.	Y.P.	M.S.	Elongation.	Elastic Limit.	M.S.	Elongation.	Y.P.	M.S.	Elongation.	Y.P.	M.S.	Elongation.	Y.P.	M.S.	Elongation.	Y.P.	M.S.	Elongation.	Charpy Impact.	Creep St'gh.	Elastic Limit.	M.S.	Elongation*
70	20	8·9	18·0	15·0	11·4	15·2	8·0	8·3	15·2	14·0	7·4	17·0	36·5	7·1	15·2	20·5	7·3	17·5	31·2	20·0	6·25	7·5	14·2	21·0
200	93	—	—	—	—	—	—	—	—	—	6·7	16·6	37·5	—	—	—	6·7	16·7	27·2	—	—	—	—	—
300	150	—	—	—	9·8	16·1	8·6	—	—	—	6·4	15·8	31·0	—	—	—	6·6	16·8	28·7	—	—	5·7	11·8	18·8
400	205	—	—	—	—	—	—	7·5	15·0	18·0	6·7	15·2	28·5	—	—	—	6·3	15·9	25·5	19·5	—	—	—	—
500	260	8·2	14·4	5·5	—	—	—	5·9	11·8	11·5	5·8	13·0	24·5	—	—	—	5·8	14·6	20·5	15·2	4·0	—	—	—
550	288	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1·9	—	—	—
600	316	7·4	15·0	9·5	8·2	9·5	3·7	—	9·0	7·0	5·8	7·3	2·5	5·6	11·4	16·0	5·6	13·2	15·7	2·2	0·72	5·0	5·4	1·1
700	370	7·4	12·7	9·5	—	—	—	—	6·7	4·0	6·0	6·0	1·0	5·5	6·8	1·5	5·5	8·3	4·0	—	—	—	—	—
800	427	6·7	10·1	3·5	—	—	—	—	4·4	2·0	4·0	4·0	0	5·3	6·4	2·0	—	—	—	—	—	—	—	—
900	482	—	—	—	—	—	—	—	—	—	3·3	3·3	0	—	—	—	—	—	—	—	—	—	—	—

* Extracted from A.S.M.E.—A.S.T.M. Symposium on Effect of Temperature on the Properties of Metals, 1931.
† Extracted from Compilation of High Temperature Creep Characteristics, A.S.M.E.—A.S.T.M., 1938.
‡ Courtesy of J. Arnott (G. and J. Weir, Ltd.).

TABLE III.—PHYSICAL PROPERTIES OF LOW-TIN CONTENT GUNMETALS AND CAST BRASSES IN COMPARISON WITH 88-10-2 GUNMETAL.

Properties.		Gunmetals.			Cast Brass.	
		88—10—2 88—8—4	86—7—5—2	85—5—5—5	Type A.	Type B.
Specific gravity		8·6—8·8	8·6—8·8	8·6—8·8	8·45—8·55	8·4—8·5
Weight per cub. in. (lb.)		0·314	0·314	0·314	0·30	0·30
Coefficient of expansion	20—100° C.	17·5	17·7	17·8	17·9	19·4
	20—200° C.	17·6	17·9	18·1	18·4	20·5
	20—300° C.	17·9	18·2	18·4	19·0	21·8
	20—400° C.	18·0	18·4	18·7	19·6	—
	20—500° C.	18·1	18·6	19·0	20·2	—
Thermal conductivity		Approx. 13—15% of that of copper at 20° C.			Approx. 18—22% of that of Cu at 20° C.	Approx. 16—20% of that of Cu at 20° C.
Electrical resistivity						

special purposes their use seems to be essential. It has been shown, for example, that in unlined bearings subject to pounding, such as are employed for railway wagon bearings and rudder bushes, etc., on ships, the resistance to deformation is markedly reduced as the tin content falls below 10%, and with the introduction of lead. It is noteworthy that the presence of up to 4% zinc has, in most instances, little effect upon frictional properties and resistance to deformation. The use of gunmetal or bronze containing around 10% tin is also considered essential for the production of high-pressure air and hydraulic valves

A and B, are not recommended for use at elevated temperatures. Corrosion and production data are given, and examples of suggested applications of both the gunmetals and cast brasses are given in Table IV.

The concluding part of this report deals with the founding of types A and B brasses, and incorporates the results of tests carried out by J. Arnott and E. J. L. Howard, while a mercury-cathode method for the determination of aluminium in brass or bronze, described by J. McPheat, is appended. The whole report is an especially important contribution on the subject under present conditions.

TABLE IV.—SUGGESTED APPLICATIONS OF GUNMETALS AND CAST BRASSES.

Type Composition.	B.S.S. No.	Suggested Application.
GUNMETALS. 88—10—2	383	To be used only for special applications, i.e., high-pressure hydraulic and air valves working between 1,000—4,000 lb. per sq. in. control and stop-valves, steering gear telemotor cylinders. Special unlubricated bearings subjected to pounding, vibration and corrosion, e.g., rudder post liners and bushes, steering gear bearings, etc.
88—8—4	—	Suitable for conditions of service intermediate between those specified for alloys of 88—10—2 and 86—7—5—2 type, e.g., hydraulic valves working between 500—1,000 lb. per sq. in. (Does not possess much advantage over alloy of 86—7—5—2 type so far as steam service is concerned.) Sea-cocks and other valves connected direct to hull below water-line.* Pump impellers. Stern tubes.
86—7—5—2	—	Suitable for all general-purpose castings subject to medium steam pressures (above 100 lb. per sq. in working pressure) and at temperatures not exceeding 500° F. (260° C.), e.g., small engine control and boiler stop-valves, cylinder cover bushes, neck rings, centrifugal pump casing, tail-shaft liners, and stern tube bushes. Hydraulic valves operating between 200—500 lb. per sq. in. pressure. Suitable for high-grade backings of lined bearings. Slip rings for electrical equipment (under 2% lead if possible).
85—5—5—5	898	Suitable for general-purpose castings subject to steam up to 100 lb. per sq. in. working pressure and temperatures not exceeding 400° F. (205° C.), and water pressures up to 200 lb. per sq. in. working pressure, e.g., screw-down valves, bulkhead and deck fittings, tee-pieces, etc., handling auxiliary steam-heatng services to galleys, pantries and thermo-tanks. Cocks, taps and sanitary fittings handling sea-water, e.g., pump-type lavatory valves. Pumping, flooding and draining valves not directly connected to hull below water-line. Sluice valves to sea-cocks. Fire-hose connections. Centrifugal pump casings. Suitable for well-supported backings of certain lined bearings, e.g., small stern tube bushes, etc.
CAST BRASSES. Type A (70—80% Cu)	—	Suitable for low-pressure fittings working under mildly corrosive conditions (not recommended for use at elevated temperatures or for conditions requiring exceptional wear and tear), e.g., cocks, taps, pipe connections and sanitary fittings for use in fresh water at pressures up to 110 lb. per sq. in. Ventilating valves. Name-plates. Lubricators. Better resistance to oils containing sulphur than gunmetal, therefore can be used with advantage for valves and fittings handling fuel oil and petrol.
Type B (62—70% Cu)	—	Non-pressure structural and ornamental castings. Pressure gauge and telegraph cases. Voice-pipe fittings and connections. Funnel fittings. Hand-wheels. Gear-case covers. Steering wheel brackets. Porthole and skylight casings. Motor-boat deck fittings. Bearing backings where a copper alloy is required and the backing need not in itself possess bearing properties.

*The use of cast aluminium bronze is more suitable, as there is no galvanic action between this alloy and steel in the presence of sea-water.

operating at 1,000 to 4,000 lb./sq. in. On the other hand, gunmetal of the 88—10—2 type is being wastefully employed for many purposes, and service conditions can be equally well met by the use of lower tin-content alloys, or even by cast brass.

These gunmetals are considered, and Table I shows a comparison of mechanical properties at room temperature of these gunmetals against Admiralty gunmetal. Table II gives the mechanical properties principally based on short-time tensile tests at elevated temperature. Considerable work has been done on cast materials for high-temperature service, and it has been shown that while short-time tensile tests indicate that the higher tin-content alloys of the 86—12—2 and 88—10—2 types are stronger than 86—7—5—2 gunmetal at elevated temperature, the latter alloy is actually more creep resistant than the former at temperatures above 250° C. Considerable data are given on creep tests, and attention is directed to the behaviour of castings at sub-zero temperatures.

Typical values for such properties as specific gravity, coefficient of expansion, thermal conductivity, etc., are given in Table III. So far as the gunmetals are concerned, there is little difference in general physical properties between 88-10-2 and the other types under review. Corrosion data are also presented, and some attention is given to the foundry characteristics of the bronzes discussed.

The mechanical properties at room temperature of certain brasses are included in Table I. Cast brasses, types

Expansion in Magnesium

THE discovery of brucite limestone in Canada and the development of these deposits, which previously had relatively small economic value, in the production of magnesia of the highest grade, was briefly mentioned in our last issue. This discovery is of great importance in the manufacture of the metal magnesium, and in assisting to supply the raw material for the great expansion in the use of this metal brought about by the war. According to a contemporary,* the United States' output of this metal in 1940 was only a little over 6,250 net tons. In 1941 this had been increased to about 16,500 tons. According to a recent statement by W. L. Balt, however, this is to be stepped up this year to approximately 362,500 tons, an expansion over 1940 of nearly sixty-fold. The realisation of this programme will far outstrip the expansion in so short a time of any metal in history.

Manufacture is being supplemented by a new process, known as the ferro-silicon process, and several new plants are being erected to use this method, in which high-grade ferro-silicon is mixed with dolomite, heated in a vacuum, whereby the magnesium is distilled and sublimed. It is estimated that about one-fifth of the total magnesium to be produced will be by this method.

*Metals and Alloys.

The Chemical and Physico-Chemical Analysis of Iron and Steel

Twelve Years' Advancement

Part II.—Papers Describing the Determination of Single Constituents

By E. C. Pigott

Aluminium

The recent extensive development of steels and irons containing alloying amounts of aluminium was hindered originally by the inadequacy of analytical methods. Several investigators evolved methods in which the aluminium is precipitated as the salt of 8-hydroxyquinoline; this reaction permitting extreme accuracy in contrast to processes in which the element is weighed as the oxide or phosphate. Subsequent to Berg's introduction of this reagent in 1927, more than 100 papers have appeared describing analytical applications, a dozen or so dealing with ferrous materials.

SEPARATION BY SELECTIVE HYDROLYSIS IN PRESENCE OF THE PHOSPHATE IRON.

Klinger. *Arch. Eisenhüttenw*, 1935, **8**, 337–43.

Molok and Waltz. *Iron Age*, 1935, **136**, No. 26, 23–5.

Pigott. *Indus. Chem.*, 1936, **12**, 360–1.
  (Rapid method applicable to all irons and steels containing small amounts of aluminium.)

SEPARATION BY MEANS OF THE MERCURY CATHODE.

(i) *8-Hydroxyquinoline.*
Dymov and Mohcianova. *Zavod. Lab.*, 1936, **5**, 718–22.

(ii) *Hydrolysis.*
Etheridge. *Analyst*, 1929, **54**, 141–4.
Peters. *Chemist-Analyst*, 1935, **24**, No. 4, 4–10.
Podkopaev. *Zavod. Lab.*, 1937, **6**, 1053–4.

CAUSTIC ALKALI SEPARATION FOLLOWED BY PRECIPITATION WITH 8-HYDROXYQUINOLINE.

Balanescu and Motzoc. *Z. anal. Chem.*, 1940, **118**, 18–26.
  (Adsorption minimised by phosphate ion.)

Bright and Fowler. *Bur. Stand. J. Res.*, 1933, **10**, 327–35.
  (Preliminary sodium bicarbonate separation.)

Klinger. *Arch. Eisenhüttenw.*, 1939, **13**, 21–36.
  (39 references.)

CAUSTIC ALKALI SEPARATION FOLLOWED BY PRECIPITATION WITH AMMONIUM HYDROXIDE.

Gerke and Kardakova. *Zavod. Lab.*, 1933, **2**, No. 7, 33–6.

Sinkai and Nagati. *J. Soc. Chem. Ind.*, Japan, 1939, **42**. (Supp. 397).
  (In tungsten steels.)

SEPARATION BY MEANS OF AMMONIUM SULPHIDE IN TARTRATE SOLUTION, FOLLOWED BY 8-HYDROXYQUINOLINE PRECIPITATION.

Gadeau. *Rev. Met.*, 1935, **32**, 398–400.

Taylor-Austin. *Analyst*, 1938, **63**, 566–92.
  (Preliminary sodium bicarbonate separation.)

AMMONIUM SULPHIDE SEPARATION FOLLOWED BY PRECIPITATION WITH AMMONIUM HYDROXIDE.

Mignolet. 15 *mr. Congr. chim. Ind.*, Bruxelles, Sept., 1935 (1936) 126–9.

WITHOUT PRE-SEPARATION OF IRON.

Heckzo. *Chem. Ztg.*, 1934, **58**, 1032.

Pigott. *J. Soc. Chem. Ind.*, 1939, **58**, 139–142.
  (Precipitation from cyanide-tartrate solution with 8-hydroxyquinoline; rapid method of general application.)

PHOTOMETRICALLY BY MEANS OF ERIOCHROMICYANINE AT πH 6

Koch. I. *Tech. Mitt. Krupp.*, 1938, 37–46.

Koch. II. *Arch. Eisenhüttenw.*, 1939, **12**, 69–80.

Zan'ko and Butenko. *Zavod. Lab.*, 1936, **5**, 415–18.

SEPARATION BY CUPFERRON; WEIGHED AS OXIDE.

Pigott. *Indus. Chem.*, 1935, **11**, 273–4.
  (In nickel-aluminium-iron alloys.)

SEPARATION BY SODIUM THIOSULPHATE AND PRECIPITATION WITH PHENYLHYDRAZINE.

Honjo. *J. Chem. Soc.*, Japan, 1936, **57**, 682–4.

Ishimaru. *J. Chem. Soc.*, Japan, 1932, **53**, 967–9.

SEPARATION BY SULPHUR DIOXIDE; WEIGHED AS THE OXIDE.

Johnson. *Iron Age*, 1933, **132**, No. 7, 14–17.

PRECIPITATION BY DIBROMOHYDROXYQUINOLINE.

Zan'ko and Bursuk. *J. App. Chem.* (U.S.S.R.), 1936, **9**, 895–8.

ELECTROLYTICALLY.

Kar. *Metals and Alloys*, 1935, **6**, 156–7.

REVIEW.

Ballay and Delbart. *Fonte*, 1938, 1163–72; *Chem. Zentr.*, 1938, II, 2309.
  (Survey of methods for special cast irons.)

DETERMINATION IN FERRO-SILICON.

Klinger. *Arch. Eisenhüttenw.*, 1934, **7**, 551–6.
  (16 references.)

DETERMINATION IN FERRO-CHROME.

Cunningham. *Ind. Eng. Chem. Anal. ed.*, 1931, **3**, 103–4.
  (Fe pptd. by cupferron; Cr oxidised $HClO_4$; Al weighed as Al_2O_3.)

DETERMINATION OF ALUMINA (Al_2O_3).

Araki. *Tetsu-to-Hagane*, 1940, **26**, 14–19.
  (Solution in 4N HNO_3; carbides decomposed by $KMnO_4$, providing greater accuracy; weighed as Al_2O_3.)

Fogel'son. *Zavod. Lab.*, 1937, **6**, 1276.
  (Solution in 33% HNO_3 containing $(NH_4)_2S_2O_8$; residue fused $K_2S_2O_7$; Hg-cathode sepn.; weighed as Al_2O_3.)

Johnson. *Iron Age*, 1933, **132**, No. 12, 24, 60, 62, 64.
  (Oxidation with (a) HNO_3, (b) 30% H_2O_2.)

Klinger and Tuche. *Arch. Eisenhüttenw.*, 1933, **4**, **7**, 615, 625.
  (Good agreement found in Br, HNO_3, HCl, and $HgCl_2$ methods; decomposition with 1 : 6 HCl recommended.)

Motok and Waltz. *Iron Age*, 1935, **136**, No. 26, 23–5.
  (Obtained as the phosphate; unsuitable for stainless steels.)

Podkapaev. *Zavod. Lab.*, 1937, **6**, 1053–4.
  (Sample decom. 33% HCl; residue fused $KHSO_4$; Hg-cathode separation; weighed as the oxide.)

Thompson and Acken. *Bur. Stand. J. Res.*, 1932, **9**, 615.
  (Solution in 1 : 2 HCl; accurate where only little nitride.)

SPECTROGRAPHIC.

Schliessmann. *Arch. Eisenhüttenw.*, 1940, **14**, 211.
  (Al_2O_3 and Al in steel and cast iron; pre-extraction in dil. HCl.)

Arsenic

Recent literature is concerned principally with precipitation in the elemental condition as distinct from the older halogen-distillation process. Arsenides in steel are insoluble in hot 1 : 4 HCl and hot (1 : 9) H_2SO_4 so that additional treatment with HNO_3 is usual. The best precipitants are sodium hypophosphite (Evans, 1929) and stannous chloride (Mazette and Agostini, 1923). The former reacts more readily and is by far the more stable.

PRECIPITATION BY HYPOPHOSPHITE WITH IODOMETRIC FINISH.

Challis. *Analyst*, 1941, **66**, 52–60.
  (Modification to preclude interference of Se and Te.)

Evans. *Analyst*, 1929, **54**, 523–35.

Fainberg and Ginzburg. *Zavod. Lab.*, 1932, No. 7, 23–9; *Chem. Zentr.*, 1934, **1**, 2318.

Fogel'son and Kalmuikava. *Zavod. Lab.*, 1936, **5**, 584–6.

PRECIPITATION BY HYPOPHOSPHITE AND FINAL WEIGHING AS
ARSENIO-MOLYBDATE.

Misson. *Chimie et Ind*, Special No., 194–5 (March, 1931).

PRECIPITATION BY STANNOUS CHLORIDE WITH IODOMETRIC FINISH
Cr, Ni, Co, V, Mo, Ti, Zr, Cu, Al, B, Mn do not interfere.

Lombardo. *Met. ital.*, 1937, **29**, 1–7.

Rabinovitsch. *Zavod. Lab.*, 1934, **3**, 211–14.

Veinberg and Piradjan. *Rep. Centr. Inst. Met.*, 1934, No. 16, 185..

COLORIMETRICALLY.

Rodden. *Bur. Stand J. Res.*, 1940, **24**, 7–11.
(Distillation with HBr and HCl; blue solution produced with ammonium
molybdate measured by means of photo-electric absorptiometer.)

Sveshaikov and Smirnova. *Zavod. Lab.*, 1936, **5**, 271–2.
(Guitzeit finish.)

Tartakovskie. *Zavod. Lab.*, 1935, **4**, 750–4.

ELECTROLYTICALLY.

James-Levy. *Russ*, 1933, **31**, 933 (Sept., 30).

Veinberg and James Levy. *Repts. Inst. Metals*, Leningrad, 1933,
No. 13, 136.
(Arsenic deposited from HNO₃—am. citrate solution on waxed Cu-electrode.)

REVIEW OF METHODS.

Stadeler. *Arch. Eisenhüttenw.*, 1935, **9**, 423–33.
(25 references.)

Beryllium

The few papers contributed offer separations alternative
to the admittedly unsatisfactory carbonate method. In
view of the difficulty of removing aluminium, it is regrettable
that this problem has not received more attention; the
oxine separation would appear to be adaptable to ferrous
analysis.

WEIGHED AS BeO.

Eckstein. *Z. anal. Chem.*, 1932, **87**, 268–72.
(Separation of Fe by KOH after oxidation of Mo, Cr, V and Mn with AgNO₃ +
(NH₄)₂S₂O₈.)

Mon'yakova and Yanovskii. *Zavod. Lab.*, 1935, **4**, 294–5.
(Separation of Fe by Hg cathode and final traces by oxine.)

Spindeck. *Chem. Ztg.*, 1930, **54**, 221.
(In Al-free steels; Cr oxidised by AgNO₃ and (NH₄)₂S₂O₈.)

Tettamanzi. *Industria chimica*, 1934, **9**, 752–5.
(Separation of Fe by cupferron.)

Colorimetric Titration.
Fischer. *Wiss Veröff*, Siemens-Konz, 1929, **8**, 1, 9–20.
(Strongly ignited ppt. of Be(OH)₂ and Fe(OH)₃ reduced in H₂, the Fe extracted
by HCl, the residue dissolved in HF, treated with NaOH and the solution titrated
with quinalizarin.)

SPECTROGRAPHIC.

Masi. *Spectrochim Acta*, 1940, **1**, 462.
(In common and special steels.)

Boron

Neither gravimetric methods nor Hg-cathode separations
were examined by investigators. As the result of modifica-
tions by Hague and Bright, distillation as methyl borate
followed by alkimetric titration has become a reliable
process. In Kar's adaptations of the quinalizarine and
curcumin tests the conditions are somewhat critical. The
removal of Fe and Al by means of NaOH in place of Na₂CO₃
was applied to ores by Scott. A spectrographic method is
described by Masi.

Hague and Bright. *Bur. Stand. J. Res.*, 1938, **21**, 125–31.

Kar. *Metals and Alloys*, 1938, **9**, 175.

Scott. *Indus. Eng. Chem. Anal. ed.*, 1932, **4**, 306–8.

Masi. *Spectrochim Acta*, 1940, **1**, 462.

Carbon

Development has been focused chiefly on combustion
processes, especially those dependent on volumetric
measurement, though spectrographic and magnetic pro-
cedures have been formulated.

HIGH TEMPERATURE COMBUSTION IN OXYGEN.
VOLUMETRIC.

Aleksandrov. *Zavod. Lab.*, 1935, **4**, 453–5.

Anon. *Chem. Ztg.*, 1937, **61**, 476.
(Eder's method modified to ensure a constant temperature.)

Dolinski. *Zavod. Lab.*, 1937, **6**, 1277.
(Apparatus for Fe Cr.)

Bogdanchenko. *Zavod. Lab.*, 1937, **6**, 369.

Evseev. *Zavod. Lab.*, 1932, **1**, No. 10, 66.

Chem. Zentr., 1935, **1**, 114.
(Modified Wurtz apparatus for several rapid consecutive estimations.)

Gerke and Kardakova. *Zavod. Lab.*, 1934, **3**, 977–83.

Kalina and Joseph. *Heat Treatment and Forging*, 1939, **25**, 169, 177.

Korovin and Yurkin. *Zavod. Lab.*, 1936, **5**, 1131.
(Improvement of Jensen (1920) method.)

Misson I. *Chimie et Indus.*, 1932. Special No., March, 326.

Misson II. *Chimie et Indus.*, 1934. Special No., April, 436.

Singer, *et al. Ind. Eng. Chem. Anal. ed.*, 1941, **13**, 115.
(Estimation in 4 mins.; absorption tube kept in balance.)

Thuravleva and Chuparov. *Zavod. Lab.*, 1940, **9**, 498.
(Modification of Jensen method.)

Williams. *Arch. Eisenhüttenw.*, 1937-8, **11**, 183.
(Ba(OH)₂ method for low carbon steels.)

Ziegler. *Amer. Electroch. Soc.*, 1929. Sept.
(Improvement of Jensen (1920) method.)

GRAVIMETRIC.

Baseau. 15me *Congr. chim. ind.* (Bruxelles, Sept., 1935), 1936, 83.

Bright and Lundell. *Bur. Stand, J. Res.*, 1930, **5**, 943–9.
(Determination in high sulphur steels; final traces of SO₃ absorbed in anhydrone.)

Festschr and Kassler. *Mikrochem.*, 1930, 170.

Johnson. *Iron Age*, 1931, 127, 549.
(Determination in rustless steels, KMnO₄ obviating the interference of sulphur.)

Shinkai. *J. Soc. Chem. Ind.*, Japan, 1938, Suppl. binding, **41**, 217.
(Absorption in soda lime.)

Taylor. *Ind. Chem.*, 1936, **12**, 372–4.
(In cast iron.)

Zindel. *Chem.-Ztg.*, 1929, **53**, 891.
(Mild steel claimed superior to Bi₂O₃, as a flux for alloy steels.)

SPECTROGRAPHIC.

Emery and Booth. *Ind. Eng. Chem. Anal. ed.*, 1935, 419.'

Gatterer and Junkes. *Lab. Astro. Specola Vaticana, Recerche
Spettroscop*, 1938, July, **1**, 1–24; *Chem. Zentr.*, 1938, II, 3281.

Schliessmann and Zanker. *Arch. Eisenhüttenw.*, 1937, **10**, 383–94.

MAGNETIC INDUCTION.

Blosjo. *J. Amer. Fdy. Assoc.*, 1939, May.
(In plain steels in 2½ mins.)

Dean. *U.S. Bur. Mines, Repts. of Invest.*, 1940, 3480, 98 pp.
(Reference to coercimetric method.)

Klinger. *Arch. Eisenhüttenw.*, 1929-30, **3**, 347.
(An accuracy of ± 0·02% claimed for Malmberg's carbometre.)

Malmberg. *Jernkontorets Ann.*, 1930, **114**, 508–45.

Soltan and Loughridge. *Phys. Rev.*, 1935, **47**, 426.
(In mild steel.)

Work and Clark. *Am. Inst. Mining Met. Eng.; Tech. Pub. No.
1132*, 1939.
(In bath samples.)

Cerium

Despite several investigations regarding the influence of
cerium on steel and iron, its determination was not con-
sidered within the period under review. Separation from
other elements of the group may be effected by either the
oxalate process or the fluoride method.

Chromium

Several recent methods involved potentiometric titration
and others, the use of internal indicators. Willard and
Young proposed *O*-phenanthroline-ferrous complex or
oxidised diphenylamine sulphonic acid, and evolved a
method in which tungsten is kept in solution as a complex
fluoride, excess permanganate being removed by sodium
azide or by sodium nitrite and urea.

REVIEW OF METHODS.

Schiffer and Klinger. *Arch. Esenhüttenw.*, 1930, **4**, 7.
((NH₄)₂ S₂O₈—AgNO₃ method is the best for low carbon steels; other steels
best pulverised and fused with Na₂O₂ and iodometric titration then applied.

TITRATION OF THE CHROMATE ION WITH FERROUS SOLUTION.

Britzinger and Jahn. *Angew. Chem.*, 1934, **47**, 456.
(Potentiometric.)

Brüggemann. *Chem. Ztg.*, 1929, **53**, 927, 947.
(In high-speed tool steels.)

Dickens and Thanheiser. *Mitteil aus dem. K. W. Inst. für Eisenf.*
1938, **20**, No. 3, 35–41.
(Potentiometric.)

Forsyth and Barfoot. *Ind. Eng. Chem. Anal. ed.*, 1939, **11**, 625.

Heczko. *Angew Chem.*, 1931, **44**, 992.
(Potentiometric.)

Hild. *Chem. Ztg.*, 1931, **55**, 895.

Hiltner and Marwan. *Z. anal. Chem.*, 1933, **91**, 401.
(In special steels.)

Kjerrmann and Bueckströn. *Jernkontorets Ann.*, 1933, **117**, 178.
((NH₄)₂ S₂O₈ method.)

Mukhina and Zolatarev. *Zavod. Lab.*, **3**, 784.
(HClO₄ method for special steels.)

Pigott. *Ind. Chemist*, 1940, **16**, 283.
(Oxidation with persulphate without catalysis by AgNO₃.)

Poolish and Sullivan. *Iron Age*, 1939, **143**, 38.
(O-Phenanthroline as internal indicator.)

Raab. *Angew. Chem.*, 1937, **50**, 327.
(HClO₄ method.)

Seuthe and Schaefer. *Arch. Eisenhüttenw.*, 1937, **10**, 549.
(HClO₄ method.)

Smith and Smith. *J. Soc. Chem. Ind.*, 1935, **54**, 185 T ; 189 T.
(HClO₄–H₃PO₄ solvent for stainless steel.)

Spindeck. *Chem. Ztg.*, 1930, **54**, 890.

Willard and Gibson. *Ind. Eng. Chem. Anal. ed.*, 1931, **3**, 88.
(HClO₄ method for steels, ores and alloys.)

Willard and Young I. *Ind. Eng. Chem. Anal. ed.*, 1933, **6**, 48.
(HClO₄ oxidation ; O-phenanthroline as internal indicator.)

Willard and Young II. *Ind. Eng. Chem. Anal. ed.*, 1933, **5**, 154.
(Diphenylamine sulphonic acid as internal indicator.)

Willard and Young III. *Ind. Eng. Chem. Anal. ed.*, 1933, **5**, 158.
(W retained in solution as fluoride.)

Willard and Young IV. *J. Amer. Chem. Soc*), 1929, **51**, 139–149 ; 149–152.
(Oxidation in hot solution with Ce(SO₄)₂ and excess titrated with NaNO₂ or Na₂C₂O₄; alternatively NaNO₃ added to excess treated with carbamide or sodium azide.)

MISCELLANEOUS.

Dietz. *Angew. Chem.*, 1940, **53**, 409.
(In steels, alloys and chromite ; iodometrically after volatilisation as CrO₂Cl₂ from H₃PO₄–HClO₄ – HCl solution.)

Taylor-Austin. *Analyst*, 1938, **63**, 710.
(Cr-compound of 8-hydroxyquinoline.)

POTENTIOMETRIC—SnCl₂ TITRATION.

Zezebiatowski. *Rocz. Chem.*, 1930, **10**, 411–36.

GRAVIMETRIC.

Pond. *Chemist-Analyst*, 1929, **18**, 11.
(H₂SO₄ : HCl : HNO₃ solvent ; Na₂O₂ to excess ; precipitation with Pb acetate.)

PHOTOMETRIC.

Dietrich. *Metallwirtschaft*, 1939, **18**, 811.
(Oxidation with HClO₄ ; iron colour suppressed by NaF.)

Koch. *Tech. Mitt. Krupp. Forschungsber.*, 1938, 37–46 ; *Arch. Eisenhüttenw.*, 1939, **12**, 69–80.
(For <20% Cr ; peroxide fusion extract treated with NH₄Cl, (NH₄)₂ HPO₄ and charcoal ; Na₂CrO₄ intensity measured after 15 mins. ; small amounts estimated by addition of diphenylcarbazide.)

Mal'tsev and Temirenko. *Zavod. Lab.*, 1941, **10**, 357.
(In steel and cast iron ; 20-min. method ; H₂SO₄–H₃PO₄–AgNO₃– (NH₄)₂S₂O₈—aliquot treated 4 ml. (1 : 2) H₃PO₄, H₂O and diphenylcarbazide, which dispels K₂Mn₂O₈ and reacts with —CrO₄.)

Pinsl. *Arch. Eisenhüttenw.*, 1936, **10**, 139.
((NH₄)₂S₂O₈—HCl—NaF ; S may interfere.)

MICROCHEMICAL.

Kassler. *Microchem*, 1930, 170.

Koch. *Tech. Mitt. Krupp*, 1938, No. 2, 37.

SPECTROGRAPHIC.

Thanheiser and Heyes. *Arch. Eisenhüttenw.*, 1937, **11**, 31–40.
(Intensity of spectral lines measured photoelectrically.)

COLORIMETRIC.

Agnew. *Analyst*, 1931, **56**, 24–8.
(Traces in steel by diphenylcarbazide.)

POLAROGRAPHIC.

Thanheiser and Williams. *Mitt. K. W. Inst. Eisenfor.*, 1939, **21**. No. 4 ; *Arch. Eisenhüttenw.*, 1939, **13**, 73.

DETERMINATION IN FeCr.

Dickens and Thanheiser. *Arch. Eisenhüttenw.*, 1933, **6**, 379.
(Potentiometric.)

Smith and Getz. *Indus. Eng. Chem. Anal, ed.*, 1937, **9**, 378.
(H₃PO₄ as solvent ; oxidation with HClO₄.)

(*To be continued*)

Metallic Copper as an Anti-fouling Medium

PAINT surfaces for the protection of under-water marine surfaces require formulation to meet a number of important requirements. The diversity of these requirements makes the problem difficult. The primer and top coat must fulfil their functions as well as be mutually compatible in forming a coherent film. In some recent tests Tuwiner and Dodge* have employed panels of steel, coated in the field, and allowed a drying period comparable with those permissible in good practice for commercial shipping. Most promising results have been found with paints formulated with pure electrolytic flake copper in one of the class of varnish vehicles with short oil length, containing coumarone-indene and phenolic resins. The best appears to be one with a vehicle of 6-gallon tung oil varnish based upon three-quarters coumarone-indene and one quarter p-phenylphenol-formaldehyde resins.

The anti-fouling compositions contain a copper bronze pigment incorporated in paste form. The paste contains 78 to 80% of electrolytically refined oxygen-free copper coated with a polishing agent of stearic acid and oily matter ; the rest is high-solvency petroleum spirits. Each composition tested contained 3 lb. of this pigment paste per gallon of paint. A quick-drying red lead paint was used as a primer, the composition of which was 68% pure red lead pigment and 32% alkyd-type vehicle. This paint, while far from ideal, appeared to be the best of a number of proprietary compositions tested.

A series of panels were painted with coats of the above red lead primer followed by a single coat of one of a number of anti-fouling composition. A 6-gallon tung oil vehicle composition based on three-fourths coumarone-indene and one-fourth p-phenylphenol-formaldehyde, was found to be the best, followed by a 4-gal. tung oil coumarone-indene vehicle.

To prove that the combination of a primer consisting of red lead in an alkyd vehicle and a top coat of pure metallic flake copper in a 6-gal. tung vehicle, based upon three-quarters coumarone resin and one-quarter p-phenylphenol-formaldehyde, was practical for commercial shipping in coastal service, a large-scale test is in progress. The *Lake Traverse* was painted. This vessel is a freighter of approximately 3,000 tons, 250 ft. long, with a 40-ft. beam. The steel hull was sand-blasted to remove old paint and rust thoroughly. The surface was very clean after this treatment, but was marred by numerous pits approximately $\frac{1}{16}$ in. deep. Three coats of the red lead alkyd primer were applied by spraying, each coat being allowed to dry overnight. Two coats of the metallic copper anti-fouling paint were then applied, the same composition being used as was used in the panel tests. The surface, approximately 20,000 sq. ft., required 60 gals. of red lead for the first coat, 50 for the second, and 45 for the third. 52 gals. of copper paint were used for each coat. The top coats leafed perfectly and gave the appearance of a brilliant sheet of metallic copper. After launching, the boat immediately sailed for the Atlantic, engaging in its usual business of carrying general cargo from the West Indies and South American ports to various ports on the East Coast of America. After five months of operation the ship had scraped her side badly and required dry-dock servicing. The hull was in perfect condition, with no sign of fouling of any kind and complete absence of film failure, except for the scraped portions, which were retouched by spot priming with the same red lead primer used initially ; the entire hull was given a single coat of copper antifouling paint. The ship was then put into charter service in Caribbean waters. At the time the authors prepared their report, six months later the vessel is still giving service with no increase in fuel consumption for maintaining regular speed.

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Malleable Beryllium

BERYLLIUM is most familiar as the essential alloying constituent of certain age-hardening alloys of aluminium and copper. Recently, pure beryllium has had a growing commercial application for " windows " of X-ray tubes and for this purpose should be vacuum-tight, malleable to permit being formed into thin sheets, and ductile at high temperatures to facilitate brazing. As beryllium has so far resisted all attempts to render it malleable through enhancement of its purity, the results of an investigation by G. E. Claussen and J. W. Shehan,* which reports the successful production of malleable beryllium containing small amounts of titanium and zirconium and describing the processing technique employed is therefore of metallurgical interest.

The research was undertaken to secure thin vacuum-tight beryllium about 0·004 in. to 0·020 in. thick, with some ductility at elevated temperatures, and also to produce malleable beryllium in curved or cupped form, because machining or grinding thin parts of beryllium, which is brittle at room temperature, is scarcely practicable. Since the lack of malleability of beryllium appeared to be caused by films of material believed to be beryllium oxide, a number of elements were alloyed with the beryllium in an effort to remove the films. Of a number of alloying elements investigated, titanium and zirconium were successful, and it was found that beryllium treated with a little of those elements could be hot-worked satisfactorily.

The raw material used for the experiments was commercial beryllium metal containing, according to spectrographic analysis, 0·1-1·0% magnesium, 0·001-0·1% aluminium, 0·001-0·1% iron, up to 0·01% silicon, up to 0·01% chromium, up to 0·01% manganese. No entirely satisfactory fluxes being available to permit melting in air, vacuum melting was selected, although any method of melting, such as under hydrogen or a flux in which the beryllium was out of contact with a reactive atmosphere, might have been as satisfactory. Two vacuum furnaces were used, both involving rubber gaskets, which remain cool during operation. In the first furnace a beryllium oxide crucible was inside a Pyrex container 3 in. in diameter, and was heated by a high-frequency coil. The second furnace consisted of a welded steel casing within which was a molybdenum-wound heating tube. The head of this furnace was cooled internally by flowing water. Both furnaces were fitted with oil diffusion pumps and with viewing glasses at the top for temperature measurements.

When a vacuum of 1 micron was obtained on the first furnace heating was commenced, the vacuum falling to 0·4 mm. to 0·5 mm. when a 200-grm. charge of raw metal was being melted over a period of 20 to 30 mins. After melting had occurred and reactions such as volatilisation of magnesium in the melt had ceased, the vacuum rose to 0·005 mm. to 0·05 mm. The heating of the resistance furnace occupied 6 hours, and the pressure never exceeded 0·05 mm., the melt being frozen under a pressure of 10 to 20 microns. As melts frozen in the crucible had large shrinkage cavities, a self-pouring principle was adopted to produce bars 1 in. diameter and 4 in. long. The charge for self-pouring was a single block of beryllium and was held in a crucible, the bottom of which was drilled to 1 in. in diameter, and below the hole was fitted a tapered ingot mould of beryllium oxide or graphite. When the beryllium had melted, the thin but strong element of oxide surrounding the melt prevented it from flowing through the melt for a minute or two, but eventually the metal flowed through the hole in the bottom of the crucible into the ingot mould, and the metal remaining in the crucible acting as a shrink head prevented piping of the ingot. The bottom of an ingot, so poured, consisted of fine grains characteristic of chill castings, whereas the upper inch or two of the ingot consisted of a few large grains extending into the shrink head. Several melts of beryllium, instead of being self-poured, were bottom poured by means of a tapered beryllium plug, fitted into a hole in the bottom of the crucible and removed at the proper moment by means of wires coated with beryllium oxide.

In view of the high purity of the beryllium, of over 99.9%, after vacuum melting, which lowers the magnesium content to one part per million or less, it was not expected that distillation or sublimation would improve the purity, but nevertheless about 200 grms. were distilled in several attempts. A charge of vacuum-melted beryllium was placed in a beryllium oxide crucible having a tightly fitted funnel of beryllium oxide placed on top of the beryllium and a hood on top of the funnel. The distillate from 100 grms. of beryllium after 2 hours at 1,550° C. weighed about 40 grms. The distillate at the top of the hood was sublimed metal consisting of myriads of tiny crystals of beryllium. Lower in the hood near the funnel was some sublimed metal that had melted or some distillate itself, while close to the funnel there was no beryllium on account of the high temperature. Neither sublimed metal or distillate was sound, and the sublimed crystals did not cohere, while overlapping oxide films were trapped in the portion which had been molten. Small particles of distillate (45 Rockwell B) hot-rolled well, but no success was had with large masses of distillate, and on being remelted the distillate became contaminated with oxide films to the same extent as undistilled metal. Great difficulty was experienced in securing a sound melt from sublimed crystals as each crystal seemed to be covered with a film of oxide which completely prevented coalescence during remelting. Distillation had therefore little effect on the purity of vacuum-melted beryllium apart from reducing the aluminium content to less than 0·001%.

To alloy beryllium with titanium in order to rid vacuum-melted beryllium of its films, 0·5% or less of titanium was placed on the top of the vacuum-melted metal. At a temperature a little below the melting-point of beryllium, a reaction occurred, the titanium and the metal in its vicinity melting and rising rapidly in temperature. After a few minutes, the hot reaction area spread across the melt, which again became uniform in temperature. Inspection of the titanium-treated beryllium showed that there were no oxide films in the lower part of the poured ingot, but that the upper part of the ingot sometimes contained oxide films. In the solid alloy, titanium appears as a beryllium titanium compound which lowered the melting-point of beryllium slightly through eutectic formation. The microstructure of the ingots suggested that the eutectic lay between 0·5 and 2·0% titanium. An alloy containing 0·125% titanium was 65 Rockwell B, while with 2% titanium the hardness rose to 80. So far as could be determined, titanium in the amounts referred to had scarcely any other effect on the other properties of beryllium.

Zirconium in about the same percentage as titanium may be used instead of titanium, and has the same influence on hot-rolling and microstructure. When zirconium was melted with beryllium, no exothermic reaction was observed. Molybdenum, tungsten, nickel and iron were found to alloy readily with beryllium, but to increase the hardness and brittleness. Aluminium and silver lowered the melting-point of beryllium, lithium volatilised in alloying, while carbon alloyed with difficulty.

Malleable beryllium-titanium alloys rolled in air at 600° to 900° C. from ⅛ in. thick to a thickness of 1/32 in., using about 20 passes and an oxy-gas flame. To avoid the oxidation which occurs in air, the beryllium was rolled in an envelope of nickel or stainless steel sheets, and was found to roll equally well whether cut longitudinally or transversely from the ingot. Grain size had little if any effect. Cupping was also carried out, using heated punches and dies. The surface of hot-rolled flexible sheet 0·004 in. thick was found to be remarkably smooth.